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# MOSQUITO CONTROL

## PRACTICAL METHODS FOR ABATEMENT OF DISEASE VECTORS AND PESTS

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## PREFACE TO THE SECOND EDITION

Two reprintings in 1943 of the first edition made it possible to correct some minor errors. However, the rapid development of new techniques of mosquito control in the past three years has made a thorough revision and enlargement of *Mosquito Control* advisable, that it may be more applicable to the requirements of our military forces now, and to the needs of occupational forces later on.

In this revision we have eliminated obsolete material and obvious errors, have modified some opinions, and have added whatever new material appeared to us to be significant. An appreciable enlargement of the book has resulted.

The selection of new material has been influenced to some extent by our experience in teaching medical and sanitary officers at the Army Medical Field Service School at Carlisle Barracks, Pennsylvania, and Navy medical officers in the Short Courses in Tropical Medicine and Sanitation at the University of California. The requirements of civilian workers have also been considered, except that time was not available to bring up to date the data in Tables 4 and 5.

An Appendix has been added on species identification and the use of entomological keys, designed to enable persons without training in systematic entomology to gain a fair understanding of the methods of identification of mosquitoes.

A list of vectors of mosquito-transmitted diseases other than malaria has been substituted for the material formerly in APPENDIX B.

APPENDIX A has been rearranged in alphabetical order, has been somewhat enlarged, and the latest nomenclature adopted. A chart presenting the more important malaria vectors throughout the world, grouped geographically and by typical breeding places, with appropriate control measures, has been added as Part II of APPENDIX A.

We are indebted to the Office of Malaria Control in War Areas, of the United States Public Health Service, at Atlanta, Georgia, for Figures 10, 11, 25–27, 32, 61, 64, 65, and 70 and for Plates I, III, V–XI; to the National Malaria Society for Figures 53–57; to Sir Malcolm Watson for Figures 49–52 and 85; to the Rockefeller Foundation for Figure 86; and to the M

A very lengthy list would be required to make acknowledgment of our obligation to all who have helped us with criticisms, suggestions, and information in making this revision. We hope that we have improved the book sufficiently to merit their approval.

WILLIAM B. HERMS
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*Berkeley, California*
*March 15, 1944*

## PREFACE TO THE FIRST EDITION

THE IMPORTANCE of mosquito control has come to be widely recognized in recent years, especially as its public health and economic values have become understood. The work is now engaging the efforts of a considerable number of men in all parts of the world. Engineers and physicians, as well as entomologists, have entered the field, and also an increasing number of men who, although without technical training, render effective service as members or as staff employees of administrative boards or commissions.

This book has been written with the needs of these various groups in mind. It is intended to be a practical handbook on mosquito abatement, not a textbook on drainage engineering or a technical monograph on entomology. It endeavors to present the fundamental principles of mosquito control, emphasizing practical application, geographic variation, and ecological differences in sufficient detail to indicate the main methods of attack on the problem. Thoughtful, observant, and ingenious men will adapt appropriate methods to the conditions or devise new methods based on scientific principles.

References to the literature are intended to be representative rather than exhaustive. Much that is valuable is presented in scientific journals to which access is difficult if one is remote from the libraries of the great universities; and to attempt to cite all material of value would give an appearance of erudition without enlightening the reader. However, we have assumed that anyone seriously engaged in mosquito abatement will own or have access to a working library of the more important or useful texts and monographs on mosquitoes, especially on the mosquitoes of the region in which he is working. Suggestions of such texts and monographs are given in APPENDIX E.

In a democracy, public work must have public acceptance, approval, and support. To be established successfully, not only must the work be technically sound, practically efficient, and properly administered, but its benefits must be appreciated and its principal objectives and methods understood by the community. Failures in mosquito abatement can usually be traced to neglect of educational measures for public education, public relations, and administrative procedures in planning, management, and finance. Thirty years of experience have taught us to keep the community constantly in mind, the people for whose benefit the work is done and on whose approval and cooperation its success so largely depends.

To attempt to make acknowledgment to all on whom we have drawn for facts, experience, and technical data would mean the preparation of a catalogue of practically all workers in this field, for we have freely used the research and experience of others in testing, supplementing, and extending our own research and experience. Our special thanks are offered to J. A. LePrince for criticism of the first draft of the manuscript; to N. H. Rector, J. A. LePrince, and Fred L. Hayes for the use of photographs; to Robert B. Van Etten for considerable assistance in the writing of CHAPTER V; to Thomas H. G. Aitken for assistance in the preparation of bibliographies and appendices; and to Margaret A. Prefontaine for faithful and meticulous care in the preparation of the manuscript.

Permission has kindly been granted by The Macmillan Company, publishers of *Medical Entomology*, by W. B. Herms (3d ed., 1939), and by G. P. Putnam's Sons, publishers of *Mosquito Control in Panama*, by J. A. LePrince and A. J. Orenstein (1916), to reproduce certain illustrations from those books.

Although the book is designed primarily for the use of men engaged in practical mosquito abatement, we hope it will also be useful to teachers of public health, sanitary engineering, and applied entomology.

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HAROLD F. GRAY

*Berkeley, California*
*June 5, 1940*

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# I

## INTRODUCTION

Mosquito abatement is a development mainly of the last forty years. Its beginnings were marked by public indifference and scepticism, even actual hostility, and by disagreement and controversy as to methods and purposes among those doing the pioneer work. Today, however, the efforts of many workers in entomology, engineering, public health, and medicine, as well as of men without special scientific training who have been drawn into the administration of mosquito abatement, have developed a body of practical experience and scientific knowledge which enables us to attack the problem with every confidence of success.

We may now definitely assert that at least in the temperate zones mosquito-borne disease can be practically eliminated, and personal comfort against the attacks of mosquitoes assured, at a cost which is moderate and thoroughly justifiable. There are a few areas of limited extent in which there are actual exceptions to this statement. There are also a number of areas in which there are apparent exceptions, but we are convinced that usually such exceptions are due to lack of skillful and thorough application of available knowledge.

In tropical regions, it is also possible to assert, mosquito-transmitted disease in limited areas under adequate control can be reduced to a matter of minor significance, and physical comfort maintained to a satisfactory degree, at an expense which is not prohibitive.

On the basis of experience[1] with *Anopheles gambiae* and *Aedes aegypti* in Brazil, it is also possible to assert that with trained personnel, sufficient equipment and materials, determination and time, it is possible to eradicate a particular species of mosquito within a limited geographical area, and to do this at costs which may prove to be less in the long run than the continued costs of suppressive (control) measures.

We also believe that in sub-arctic and high altitude regions satisfactory control of pest mosquitoes in limited areas may be obtained at a fairly reasonable cost. However, further study and experiment, and actual practical trials are necessary before such success can be assured. The difficulties at present appear to be great, but intelligent application of knowledge to the problem should produce practical results of value.

### Origins of mosquito control

The present ability successfully to combat mosquitoes has been achieved only as a result of long effort and much study and experiment, of trial and error, of success and failure. Very little was known, even to scientists, concerning the biology and habits of mosquitoes prior to about 1880. In 1879 Patrick Manson demonstrated the agency of the mosquito in the transmission of filariasis. This discovery turned the interest of research men to mosquitoes as vectors of disease, and as a result the biology of these insects began to be studied more intensely. In 1892 L. O. Howard[2] of the United States Bureau of Entomology suggested the application of kerosene to water for the purpose of killing mosquito larvae and pupae. He popularized an old idea, for an editorial[3] in the Philadelphia "Daily Advertiser" of August 29, 1793, suggested the use of oil for this purpose. Little attention was paid to the idea until Ross, Grassi, Celli, Manson, and others in 1897–99 proved *Anopheles* mosquitoes to be the transmitting agents of malaria; and Reed, Carroll, Agramonte, and Lazear in 1900 indicted *Aedes aegypti* as the vector of yellow fever.

Although Watson[4] in 1901 began his remarkably successful malaria-mosquito control work in Malaya, what really caught public attention was the work of Gorgas in stopping yellow fever in Havana in 1901, and the subsequent work of Gorgas and LePrince in controlling malaria and yellow fever in the Panama Canal Zone. By means of mosquito abatement campaigns, many cities in tropical America were gradually freed from yellow fever, with incidental reductions in the prevalence of malaria. LePrince and Orenstein wrote the story of that work in 1916[5] and their book abounds in useful information, keen observation, and shrewd comment, much of it still valuable today.

In 1901 appeared L. O. Howard's treatise, *Mosquitoes: How they live; How they carry disease; How they may be classified; How they may be destroyed*, which was of great value in spreading popular information. In 1902 control was begun at Ismalia on the Suez Canal, and within a short time this fever spot lost its former unsavory reputation. In the same year appeared Ronald Ross's small book, *Mosquito Brigades and How to Organise Them,* which gave practical and workable directions as to methods of mosquito abatement. G. M. Giles's *Handbook of the Gnats and Mosquitoes* also appeared in 1902.

Public interest in the United States was stimulated by the appearance of J. B. Smith's report on the mosquitoes of New Jersey in 1904, and by the beginning of abatement work against the famous Jersey mosquitoes. The prompt suppression, by means of mosquito abatement measures, of the 1905 New Orleans outbreak of yellow fever still further increased popular interest in mosquito abatement.

Salt-marsh mosquito abatement on the Pacific Coast began at Burlingame, California, in 1905.[6] In 1910, the writers of this book performed the first malaria-mosquito control work in an endemic area in the United States, at Penryn, California.[7] This demonstration that malaria could be controlled by mosquito abatement was followed by similar work at Oroville and at Bakersfield, California, in the same year. In 1912 the first malaria-mosquito control work on an irrigation district in the United States was performed by Thomas H. Means[8] at Los Molinos, California, with the advice of the writers.

E. H. Ross's *Reduction of Domestic Mosquitoes* in 1911 called attention to the nuisance phase of domestic mosquito breeding, as contrasted with disease prevention where vector species are present, and offered practical plans for abatement under urban conditions, particularly in warm climates.

In 1913 H. R. Carter of the United States Public Health Service[9] began malaria surveys in Virginia and North Carolina. In 1914 a federal appropriation of $16,000 was provided for malaria investigations by the Public Health Service: twenty-two surveys in seven states and three malaria control demonstrations were made in that year. In 1916 very successful demonstrations of malaria-mosquito control were made by the Public Health Service in cooperation with the International Health Board at Crossett[10] in Arkansas. The United States Public Health Service did distinguished work in this field: from 1914 to 1928 it directly or cooperatively conducted malaria surveys and investigations in 667 communities in twenty-four states, including malaria-mosquito control in 343 communities in seventeen states.

## Mosquito species

It is unfortunate that in the minds of so many persons mosquito control is simply a matter of squirting a little oil here and there on water. Effective control is actually highly complex in its details, even though its main principles can be stated in a few relatively simple generalizations. The complexities of the problem are due in part to the large number of known species of mosquitoes, which have marked variation in preferences of breeding places, in feeding and pestiferous habits, in flight range, and in their relation to disease transmission. There are at present more than 1400 described species in the world. All are grouped, on the basis of anatomical structure, in the family Culicidae, and for practical purposes are divided into four tribes: 1) the Culicini; 2) the Aedini; 3) the Anophelini; and 4) the Megarhinini. Ordinarily the Aedini are classified under the Culicini, but because of their special breeding habits and other striking differences we[11] prefer to set them apart as a distinctive group. Figure 1 displays the four stages of metamorphosis of typical species of the three more common tribes.

In the adult Culicini, the palpi (paired appendages, one on each side of the proboscis) of the female are less than half as long as the proboscis, in the male they are as long or longer; the scutellum (the rear terminal plate, subhemispherical in form, on the upper side of the thorax) is trilobed; pulvilli (pad-like cushions between the claws on the feet) are present; the abdomen is usually blunt; and the eggs are laid in clumps or rafts, usually on the water surface.

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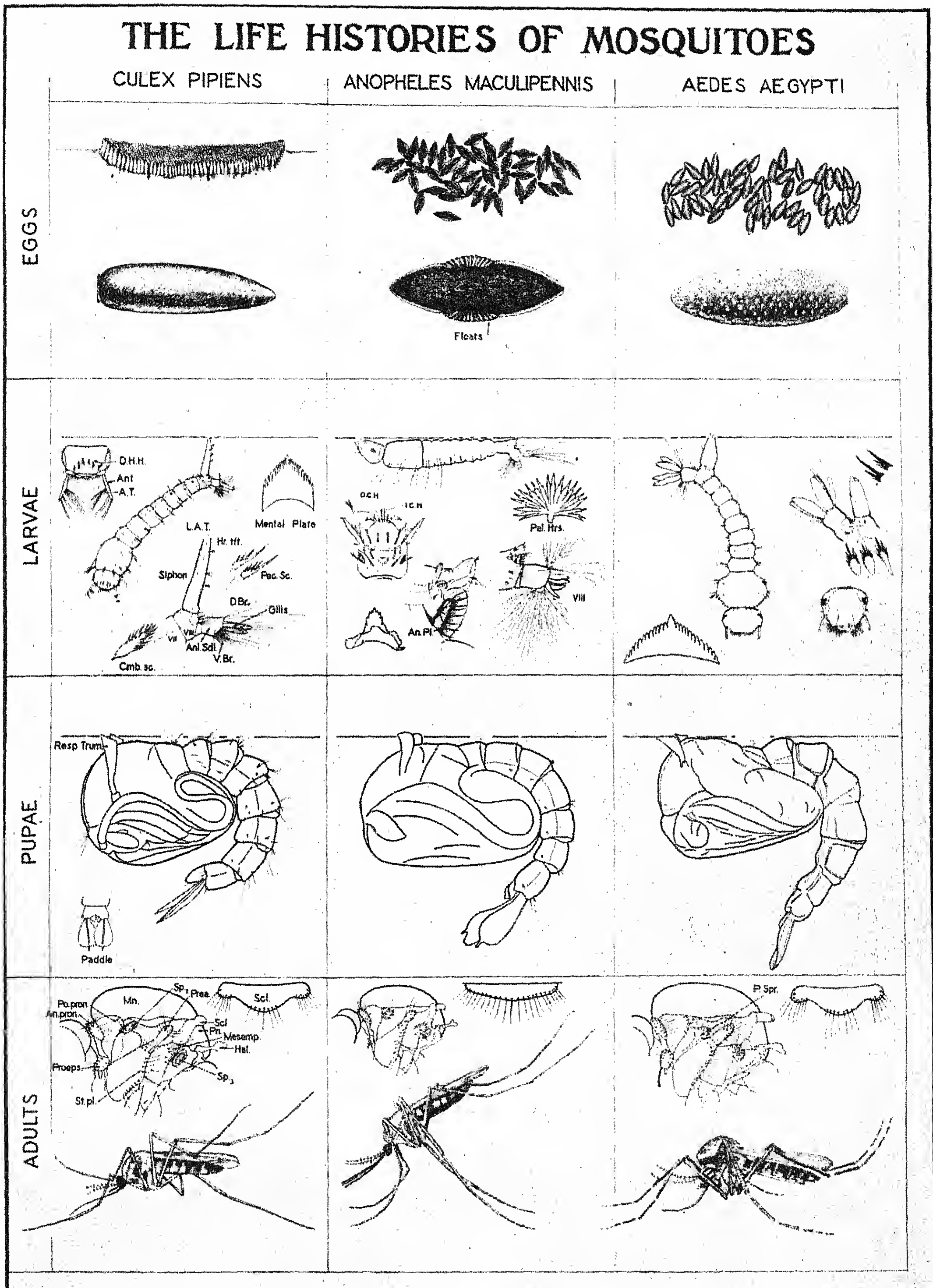
Figure 1. Morphological details and life histories of three genera of mosquitoes: *Culex*, *Anopheles*, and *Aedes*

*Explanation of the abbreviations:* An. Pl., anal plate; An. pron., anterior pronotal setae; Anl. Sdl., anal saddle (dorsal plate); Ant., antenna; A.T., antennal tuft; Cmb. sc., comb scale; D. Br., dorsal brush; D.H.H., dorsal head hairs; Hal., haltere; Hr. tft., siphon hair tuft; I.C.H., inner clypeal hair; L.A.T., lateral abdominal tuft; Mesemp., mesepimeral setae; Mn., mesonotum (tergum$_2$); O.C.H., outer clypeal hair; Pal. Hrs., palmate or float hairs (tuft); Pec. Sc., pecten scale; Pn., postnotum; Po. pron., posterior pronotal setae; Prea., prealar setae; Proeps., proepisternal setae; P. Spr., postspiracular setae; Resp. Trump., respiratory trumpet; Scl., scutellum; Sp., spiracle; St. pl., sternopleural setae; V. Br., ventral brush. (From W. B. Herms, *Medical Entomology*, 3d ed., New York: Macmillan, 1939.)




*Courtesy The Macmillan Company*

Several species of the Culicini are known to transmit disease. *Culex pipiens* transmits a minute worm, *Dirofilaria immitis*, which causes a disease known as "heartworm" in dogs, cats, and various wild carnivores. The tropical disease known as Bancroft's filariasis (with its associated disease, or sequel, elephantiasis) is caused by minute worms (*Wuchereria bancrofti*), the adults of which are found in the lymphatic system of infected humans, and the larval worms in the peripheral circulation, and is transmitted by many species of mosquitoes, of which *Culex quinquefasciatus* (= *fatigans*) and *Aedes scutellaris* (= *variegatus*) are probably the principal vectors.

The viruses of encephalitis are transmitted by several species of mosquitoes, among which *Culex tarsalis*[12] apparently plays an important part in the transmission of western equine virus, and *Culex pipiens molestus*[13] in the transmission of the St. Louis virus.

As a group, however, the Culicini are of importance chiefly as pests. They include more than 500 species classified under twenty genera. *Culex pipiens molestus*, the house or domestic mosquito in temperate climates, and its close relative *Culex quinquefasciatus* in the tropics and sub-tropical regions, are probably the best known and most ubiquitous members of this group.

In the Aedini, the female palpi are short and the scutellum is trilobed as in the Culicini, but the abdomen of the female is pointed; post-spiracular bristles are present; pulvilli are absent or hair-like; and the eggs are laid singly, seldom on the water surface, usually upon ground which will later be flooded, or upon surfaces above or adjacent to water.

There are over 500 species in the tribe Aedini, in two principal genera, *Aedes* and *Psorophora*. The genus *Aedes*, which is the more important, includes many of the most formidable mosquito pests, such as the salt-marsh group, the arctic group, the flood-water group, and the snow or boreal group. *Aedes aegypti*, which is domestic in habit and breeds in artificial containers of water in and about human habitations in tropical and sub-tropical regions, is the most important disease vector of this genus, as it transmits yellow fever, dengue, and possibly encephalitis. *Aedes albopictus* is an important vector of dengue. Other members of the genus *Aedes* (also *Haemogogus*, etc.) transmit jungle yellow fever.[14] The western equine virus of encephalitis is transmitted by several species of *Aedes*, among them being *Aedes nigromaculis* and the fresh water form of *Aedes dorsalis*.[15]

The genus *Psorophora* includes several species of pest mosquitoes commonly known as gallinippers.

The tribe Anophelini is distinguished by long palpi in both sexes; the scutellum is rounded, without lobes; there are no pulvilli; the larvae do not have a prominent breathing tube, or siphon, as in the Culicini and Aedini; and the eggs are laid singly on the surface of the water.

The tribe Anophelini is divided into three genera, *Chagasia*, *Bironella*, and

*Anopheles*. The first two of these are unimportant. The genus *Anopheles* comprises about 160 species, and is of great interest because members of this genus are the transmitters of malaria, one of the most important of all diseases affecting man.

Within single species of *Anopheles*, for example *Anopheles maculipennis*, there are several sub-species or varieties, which differ principally in breeding preferences or food habits, but have very slight anatomical differences; in fact, the only clear differences may be in the male terminalia or the eggs. This sub-specific differentiation adds to the complexity of the mosquito control problem.

The members of the tribe Megarhinini are tropical flower feeders which do not suck blood, and are of no apparent economic or medical interest. Some fifty species are included in this group.

GENERAL PRINCIPLES OF MOSQUITO ABATEMENT

When we contemplate the great diversity in types of breeding places, in food preferences, in flight habits, in ability to transmit disease, in economic effect, and in many other ways, among the many species of mosquitoes, we begin to realize the complexity of the problem of controlling these insects. Generalized rules of thumb are here not only inadequate but they are definitely detrimental to successful control. Success in mosquito abatement depends upon exact knowledge of the species of mosquitoes in the particular region to be placed under control, of the habits of each particular species or sub-species, and of the appropriate methods for the abatement of each species. Special attention should be directed to the use of naturalistic control methods (see APPENDIX C, sub-head III) which aim to effect, at relatively small cost, simple changes in environment to make it unsuitable to the breeding of the particular species in that region. In the presence of a mosquito-transmitted disease a selective attack (*Species Sanitation*, CHAPTER XVII) against the vector species is of primary importance, especially where limited funds make it impractical to attempt a program for the abatement of all types of mosquito breeding.

In some cases a grouping of local mosquito species into ecological associations based on breeding-place types may be a useful concept in the practical application of control measures.

The primary purpose of all mosquito abatement is to reduce or minimize the production of mosquitoes. This is principally a matter of reducing or eliminating the water in which mosquitoes breed, or by appropriate naturalistic methods rendering such water unsuitable for mosquito breeding. If, after this has been accomplished to the greatest practical extent, there still remains some mosquito breeding, then this residual production must be controlled by supplemental measures, such as the application of oils, Paris green, or other larvicides. But the use of oils and larvicides for the destruction of the aquatic stages of mosquito life must always be looked upon as a secondary method of attack, the necessity for which should be reduced to a minimum by the primary methods of drainage, filling, constant level flooding, controlled reflooding, and other methods hereinafter described.

Perfection of detail may not be as important as continuity of effort. Except in a few unusual cases, a sustained attack, year after year, will produce better ultimate results than an intense attack in one year followed by comparative neglect and inaction.

### Mosquito abatement and disease prevention

In the prevention of disease, one school of thought has held, so far as malaria is concerned, that quininization is the principal preventive measure and has neglected mosquito abatement or done it perfunctorily as a secondary matter. Perhaps the most extensive experience to date with both mosquito abatement and medication is that of Sir Malcolm Watson, who wrote[10] as follows:

> . . . while drugs can cure malaria, no drug so far known can prevent infection. While there are hundreds of places in which malaria has been abolished by the destruction of mosquitoes, there is no example of a place in the tropics being freed from malaria by the means of drugs alone.
>
> In 1910 (R. Ross, 1910) I published the following conclusions reached as the result of practical experience on estates and elsewhere over a number of years:
>
> That quinine given regularly greatly reduces the sick- and death-rate of those exposed to malaria.
>
> That doses of less than six grains daily are of little value if the malaria be intense—say where the spleen rate is 75 per cent or more.
>
> That when given in 10-grain doses on six days out of seven, or in 20-grain doses when a coolie has fever, or is in such bad health that he does not feel inclined to work, between 20 and 30 per cent of those taking the drug will still be found with parasites in their peripheral blood.
>
> That the use of quinine can, therefore, never result in the abolition of malaria, or even make any material reduction in the liability to infection in a malarious locality.

Extensive experiments with the new drugs atebrin and plasmoquin have led to the same conclusions. Not long ago some one wrote in the *Lancet* that those of us who carried out anti-malarial work, had not realized the danger of gametocytes, circulating in the blood, and the necessity of sterilizing the blood by drugs. The answer is that the part played by the gametocyte was fully realized; and that we tried and failed to sterilize the blood (Watson, 1911) and so far no one has been more successful. Indeed, most of those who have been engaged in Malaya, India and Europe in the prevention of malaria by the destruction of mosquitoes are convinced that it is cheaper to prevent the disease in most places by this method, than to cure the sick. What is holding up the work is not so much the lack of money as a want of knowledge of the biology of the dangerous species of mosquitoes, and of a staff conversant with the technique of mosquito control.

Watson's matured conclusions may be compared with Hackett's[17] views, that to keep a population free from gametocytes by drug administration is a practical impossibility and that, where mosquito control is feasible, mass treatment with drugs is not likely ever to be a satisfactory substitute.

In recent years the trend in the tropics has been toward more effective mosquito abatement, although in many areas it has been directed only against either vector *Anopheles* or *Aedes aegypti*. It is interesting to note that Boyd,[18] as a result of experience in Brazil, believes that in general malaria control through anti-anopheline work can be successfully carried on under tropical Brazil conditions, at a cost that the local *municipios* can well afford, except possibly in areas of intense local infection and extreme natural difficulties.

It may be a fair statement that in tropical areas under American, and to a considerable extent also under English, influence emphasis has been laid on mosquito abatement in the prevention of mosquito-transmitted diseases, whereas in tropical areas subject to Italian, French, and Dutch influence, the emphasis has been on suppressive medication, with mosquito abatement in a minor role, or neglected. With the help of the Rockefeller Foundation, Italy gave considerable attention to mosquito abatement, with good success, to some extent as a result of the comparative work done in Sardinia.[19]

It is interesting to note, in passing, that some tropical areas have been free from mosquitoes until their introduction by man within historical times. For example, the Hawaiians had no native word for mosquito: *Culex quinquefasciatus* was introduced into the islands in 1826 at Tahaina, Island of Maui, by the ship Wellington, from San Blas, Mexico,[20] and *Aedes* species at some later unascertained date. It is easy to understand how *Culex quinquefasciatus*, because of its habits, could be carried by the old sailing ships in their open water barrels. With modern airplane transportation, the probability of introduction of mosquito species into new areas is increasingly possible.

For many years now the abatement of mosquitoes which are disease vectors has been fairly widely recognized as important, and considered to be a legitimate and essential factor in the protection of the public health. But the control of what may be termed "pest" mosquitoes, in the interest of public comfort, and to guard against economic loss, has received less attention and public support, except in comparatively few areas, mostly in the United States. The long-known transmission of filariasis by mosquitoes (some 38 species have been incriminated) and recent developments in the epidemiology of certain virus diseases, especially encephalitis, which has been demonstrated to be transmissible by several species of *Aedes* and *Culex*, raise the question what species of mosquitoes are merely pests. If several of our pestiferous *Aedes* species are also carriers of diseases, where can we draw the line between mosquito abatement for the protection of the public health, and mosquito abatement for the promotion of comfort or the prevention of economic loss; and is it necessary or advisable to draw so fine a line? Time and patience in research will be necessary to unravel some of these complex questions, but the existing problem may be concisely and we believe reasonably summarized as follows:

Several species[21] of *Culex, Aedes,* and *Culiseta* (*Theobaldia*) mosquitoes transmit encephalitis from animal to animal and from animal to man.

Filariasis is transmitted by a wide variety of mosquito species, several of which are important as pests.

While the epidemiology of poliomyelitis (infantile paralysis) is not clearly understood, the possibility that this disease is transmitted by insects (perhaps mosquitoes) has been neither proven nor disproven. Some epidemiologists have suggested mosquito abatement as a legitimate method for the control of poliomyelitis. However, we have recently seen one circumscribed and isolated outbreak of poliomyelitis in which mosquitoes played no part.

The problems of mosquito abatement today are principally: the extension of effective measures into all areas where they are necessary for the health, comfort, and economic welfare of man; the development of greater efficiency in our methods of abatement so that the best results will be achieved at the lowest cost possible; and the increase of public understanding of the principles, methods, and value of the work. We have made long strides in the last forty years—much remains to be done.

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## II

## IMPORTANCE OF MOSQUITOES

Few people who have not studied the mosquito problem have any conception of its importance, both in relation to health and as an economic factor in human existence. Yet mosquitoes take their toll as certainly and as measurably as the pests affecting crops or domestic animals.

In malarial areas the disease-transmitting mosquito exacts an initial toll amounting to the value of the lives lost, the cost of medical care, the loss of working time during illness, and the loss of working efficiency during the prolonged period of lowered human vitality. The secondary effects of malaria, and to a less extent the annoyance caused by anopheline mosquito prevalence, cause additional economic damage in these areas by hindering the conduct and development of agriculture, of industry, and of business, and thereby limiting or depressing the value of property and the general prosperity of the community.

Explosive epidemics of yellow fever or dengue, both mosquito-transmitted diseases, cause serious economic damage and disruption of community life, as revealed by historical accounts of such epidemics.

The disability and disfigurement caused by filariasis are important factors in many tropical and sub-tropical regions.

The outcome of wars and the conduct of campaigns have been profoundly modified by malaria. An entire Allied army was immobilized at Salonika in 1917 by an extensive epidemic of malaria.

Extensive economic damage to infested communities may also be caused by excessive prevalence of various species of mosquitoes which are not known vectors of disease. Such species are generally designated as pest mosquitoes, to distinguish them from disease-vector mosquitoes. The economic damage caused by pest mosquitoes affects agriculture, industry, recreation, and property values approximately in proportion to the intensity of the infestation.

### *COST OF MALARIA*

Considered on a world-wide scale, malaria is one of the two or three most important of the diseases affecting man, and probably causes the greatest economic damage of all human diseases. Malaria ranks high in the United States among the infectious diseases, particularly in the southeastern states. The 1938 report of the committee on population problems of the National Resources Committee[1] published an estimate of 1,500,000 cases in this country in 1932 when the prevalence of malaria was at a low ebb, and 2,700,000 cases in 1934 when its prevalence was higher than it had been for years. The same report shows an estimate of one death for every 600 cases of malaria in this country. This is a low case-fatality rate, but the disease is of serious social and economic importance in infected areas not only because of its prevalence but because of its debilitating effects. Dr. H. R. Carter[2] estimated that for each death from malaria there were at a minimum from 2000 to 4000 sick days, and that the loss of efficiency might be two or three times greater. This estimate was purely an approximation for average conditions in southeastern United States; the loss for a particular area may vary widely from any average estimate.

The numerous estimates that have been made of the losses caused by specific mosquito-borne diseases in various areas have for the most part been based on assumptions and averages, and are not always convincing because they are after all mere approximations to the probable losses. Generally, the estimate has been based on a recorded number of deaths from malaria, an assumed average economic value of human life, an assumed case-fatality ratio, an assumed percentage reduction in earning power applied to an assumed average earning capacity, and an assumed price per acre of depreciation in value on an assumed number of acres. It is probable that only the assumed number of acres would withstand critical detailed analysis.

Probably the most brilliant and thorough study of economic loss due to a mosquito-transmitted disease has been presented in a remarkable article by Colonel J. A. Sinton,[3] Director, Malaria Survey of India, on the economic and social effects of malaria upon the people of India. The entire article is worthy of intensive study, as it presents a wealth of facts and statistical matter, together with shrewd comments thereon. There is also a very complete and valuable bibliography. In his conclusions Sinton points out that in an ordinary year in India at least one hundred million persons suffer from, and one million succumb to, the direct ravages of malaria; and that by its indirect effect in lowering the vitality of the afflicted whereby many contract other diseases, malaria is almost certainly responsible for another one million deaths and for a morbidity of between twenty-five and seventy-five millions annually. Apart from all humanitarian aspects of the problem, Sinton estimates its economic importance as follows:

> Malaria gives rise to the greatest economic problem with which India is faced. The financial losses to the individual and family alone have been calculated at not less than Rs. 11,000 lakhs, or about £80 million sterling, per annum. This is apart from the effects of the disease upon all aspects of the labour problem, and thus upon the fullest exploitation of the natural resources of the country and the successful development of her manufacturing and other industries. While it is not possible to evaluate with any degree of accuracy the immensity of these direct and indirect losses, there is little reason to doubt that they must run into unbelievable millious of pounds sterling each year. . . . It has been shown that malaria caused incalculable losses to agriculture, industry and commerce, mainly through its direct and indirect action upon different aspects of the labour problem. The most important industry of India, namely agriculture, is most markedly affected, and the disease gives rise to a retardation of agricultural developments, and sometimes to the abandonment or decline of this work in very fertile, and potentially rich areas. . . . The disease not only results in a decrease of revenue (to the Government) but also in an increase in the cost of administration. Having taken these huge losses into account, it has been shown that wisely planned antimalarial operations are paying propositions, from which there is often a direct financial profit upon the money invested, and from which there is certainly an indirect profit in the effects which such measures have on the general prosperity of the community. . . . The widespread prevalence of malaria is almost certainly the most serious economic and social problem of India. . . . The labour problem and the malaria problem are synonymous, in that this disease is the main cause of inefficient and deficient labour. . . . The problem of existence in very many parts of India is the problem of malaria. . . . It constitutes one of the most important causes of economic misfortune, engendering poverty, diminishing the quantity and quality of the food supply, lowering the physical and intellectual standard of the nation, and hampering increased prosperity and economic progress in every way.

The records of many places throughout the world give evidence of the tremendous cost of mosquito-transmitted disease, and a few illustrations, usually with the results obtained by mosquito control, will be presented.

## Results of effective malaria control measures

The beneficial results from reasonably adequate malaria control measures, in which *Anopheles* control was generally a major measure, have been demonstrated in many parts of the world. A few examples, taken principally from tropical regions, follow.

In 1901 an epidemic of malaria[4] occurred in Klang and Port Swettenham in the Federated Malay States. In a combined population of 3,500, at least 582 deaths (of which about 380 were diagnosed as malaria) occurred in that year. Business was practically suspended, and Port Swettenham was ordered closed only two and a half months after this new port had been opened. But due to an intensive campaign of sanitation, including mosquito control, the number of deaths dropped to 144 in 1902, of which about 70 were due directly to malaria, and as a result the port was not closed. Since 1902 effective mosquito control has kept malaria in these two towns at a relatively low rate.

Singapore[4] is an example of what can be done under difficult natural conditions. In 1911 it had a total death rate of 50.9 per 1,000 population (average for 1892–1911 was 42.3). Anti-malaria measures were begun in 1911, and malaria, which had been the principal cause of death up to that time, gradually declined until in 1939 the President of the municipality was able to say that "Malaria has been absolutely stamped out. It would be a very unfortunate resident who contracted malaria now."

At Carey Island[4] in Malaya, a rubber estate of 18,000 acres and 5,000 population, malaria control has been in effect since 1906. Since 1912 no European has contracted malaria on the estate, and during the five years prior to 1942 the hospital admission rate for malaria among native laborers was but one-tenth of one per cent.

The Roan Antelope Copper Mines[4] in Africa had in 1929 a high death rate from malaria, complicated by dysentery, typhoid fever, and pneumonia. As a result of the application of various sanitary measures, including mosquito control, the total death rate has fallen from about 22 per 1,000 in 1929 to 6.5 in 1941. In 1940 there were no deaths from communicable disease, and the mine was able to get an abundance of labor.

Concerning the construction of the Lower Zambesi Bridge in Africa, the London Times of October 31, 1934 reported in part as follows:

> "The Lower Zambesi has for centuries been notorious for deaths from malaria and blackwater. The Cleveland Bridge Company determined to make health a primary consideration. A rigorous and comprehensive control system was inaugurated, and, as a result, during three and a half years of construction there has not been a single case of malaria in the camp area among all the European employees who were brought straight from Britain. This is a wonderful record, and an example of what might be done for tropical Africa, given time, organization, and finances."

The bridge was completed in less than the contract time, and the expenditures for mosquito control proved to be a definite economic gain for the contractor.

The annual reports of the India Branch of the Ross Institute of Tropical Hygiene are replete with detailed illustrations of the benefits of malaria control on tea estates, jute mills, sugar factories, mines, and elsewhere, in various parts of India.

One report from a jute mill is indicative. This mill prior to 1934 furnished free supplies of quinine to its employees. Beginning in 1934 the mill carried on mosquito control measures as advised by Dr. G. C. Ramsay. The mill manager in 1941 reported[5] as follows:

> "The precautions which have been taken to combat the ravages of malaria have been quite successful as can be witnessed by the healthier workers now employed and the fact that labourers are not now migrating 'en masse' as was the rule previous to malaria prevention measures being taken up. The money which the Mills Company has spent on malaria work has been a blessing to all human beings in their employ and I am sure they have been fully recompensed for their outlay by receiving better production from the machines operated by people who have been restored to health after many years of suffering. I may mention that records of the mill show that in 1932 before recommendations were made to carry out the anti-malaria work, the spleen index was 20 per cent; today it is only 3.6 per cent."

An even more notable result was reported[6] on a tea estate at Sylket, Assam. In 1931, before mosquito control, the malaria cases were 125, and the spleen rate was 74 per cent; in 1941 the malaria cases were 31, and the spleen rate was 7 per cent.

One of the most effective control projects has been on a large group of tea estates in northern India (personal communication from Sir Malcolm Watson). Prior to commencing anti-malaria work in 1933, labor recruiting cost about Rs. 25,000 per year. At present no recruiting has to be done, and Indians on adjoining lands now ask permission to live on these estates. The malaria control work (anti-*Anopheles*) costs about Rs. 5000 per year. The cost of production of tea has been reduced 1.12 annas per pound, with a gross saving on the whole crop of about Rs. 80,000 per annum. Men's wages were increased from 4 to 5 annas per day, women's from 3 to 4 annas per day. (Note: one rupee = 16 annas; 1 anna = 12 pies. In 1941, one rupee was equivalent to about £0–1–6 English or $0.32 American money.)

The Ross Institute of Tropical Hygiene (affiliated with the London School of Hygiene and Tropical Medicine) is supported in large part by contributions from industries and businesses with tropical properties or interests. It is obvious that these contributions would not be continued year after year if the research, services, and teaching of the Institute did not produce worthwhile results of economic advantage to the donors.

### *SUGGESTIONS FOR ESTIMATING ECONOMIC LOSS*

The economic loss in mosquito-infested communities can, we believe, be estimated with sufficient accuracy for all practical purposes. However, a creditable statement even of rough estimates cannot be made by mere guesswork; actually it requires a considerable inquiry and a well-planned investigation made with the cooperation of industrialists, merchants, physicians, public officials, and the public generally, and may call for a house-to-house canvass. It should be sufficiently thorough to permit the deduction of intelligent approximations; and should preferably be stated in terms of probable maximum and minimum economic losses so as to exhibit the probable range of costs of mosquitoes or of mosquito-transmitted disease.

In estimating the economic damage done by mosquitoes, a distinction should be made between losses caused by mosquito-transmitted disease and losses which are not connected with disease. In an area in which the mosquito is a known vector of disease, the analysis of economic loss should include the following items:

1. Value of lives lost
2. Cost of medical care and medicines
3. Labor losses
    a) Loss of working time
    b) Lessened efficiency of labor
4. Property losses
    a) Depreciated real estate
    b) Losses on forced sales of property
    c) Depressed rentals
5. Loss of crops or other products of labor due to inability to work at the proper time
6. Cost of moving in and out of infested areas

In an infested area in which the mosquito is not a known vector of disease, the items above numbered 3 to 6 inclusive should be considered in an analysis of economic loss; and account should also be taken of losses of revenue in summer resorts, hotels, golf clubs and other outdoor amusements, if any of these are established in the area.

The following comments and illustrations may be helpful for securing general estimates of loss under the various items.

### Deaths

Various studies have been made of the economic value of human life, based on average per capita income, average age of the population, and average expectancy of life. All three factors will vary in different localities. The average income in a particular area, for example, may differ considerably from the national average. It should be possible to secure data for the local figure from the Bureau of Internal Revenue in the United States, or its equivalent in other countries. Of the three factors, the average age of the local population may be the most difficult to obtain, but probably can be approximated from census figures. Insurance companies also should be able to furnish data for the average age as well as for the average expectancy of life. If figures for the three factors can be obtained, the estimated economic value of a human life in a given locality would then be the average per capita annual income multiplied by the number of years of expectancy of life at that age which is the average age of the population. When such a figure is applied to a number of deaths, from malaria for example, it should be remembered that the result will be only the roughest kind of estimate.

### Cost of medical care

The best type of estimate of economic loss from a disease in a particular locality is that based on a detailed house-to-house canvass of the locality, in which the pertinent available facts are obtained and analyzed. One of us[7] had the opportunity to make such an investigation with respect to malaria in the Anderson-Cottonwood irrigation district in California in the winter of 1918–19. The economic loss due to the cost of medical service and medicines in the various parts of this district is given in Table 1.

The malaria incidence in one section of this district (town of Anderson) was studied by S. B. Freeborn[8] in June 1919. His malaria index made at that time is shown in Table 2.

In view of the fact that the survey was made in June and that the maximum malaria intensity normally occurs in September in California, the incidence figures obtained by Freeborn corroborate very

Table 1. Malaria costs in 1918, Anderson-Cottonwood Irrigation District, Shasta County, California

| | Anderson town | Anderson section | Churn Creek section | Ball's Ferry section | Cottonwood town | Cottonwood section | Entire district |
|---|---|---|---|---|---|---|---|
| Families | 94 | 75 | 19 | 12 | 46 | 14 | 260 |
| Persons | 379 | 316 | 98 | 54 | 176 | 58 | 1,081 |
| Persons per family | 4.03 | 4.21 | 5.16 | 4.5 | 3.8 | 4.14 | 4.16 |
| Persons having malaria symptoms in 1918 | 254 | 207 | 60 | 32 | 25 | 12 | 590 |
| Percentage having malaria symptoms in 1918 | 67.0 | 66.5 | 61.0 | 59.0 | 14.0 | 20.0 | 54.5 |
| Cost of medicines | $ 504.25 | $ 736.75 | $117.00 | $ 52.00 | $ 56.50 | $14.00 | $1,480.50 |
| Per family | 5.36 | 9.82 | 6.16 | 4.33 | 1.23 | 1.00 | 5.70 |
| Cost of medical service | 359.00 | 1,220.00 | 79.00 | 69.00 | 100.00 | 12.00 | 1,839.00 |
| Per family | 3.83 | 16.28 | 4.16 | 5.75 | 2.18 | 0.86 | 7.10 |
| Labor loss* | 948.00 | 3,684.00 | 218.00 | 60.00 | – | – | 4,910.00 |
| Per family | 10.10 | 49.10 | 11.48 | 5.00 | – | – | 18.90 |
| Cost of malaria in 1918 (for three items given above) | 1,811.25 | 5,640.75 | 414.00 | 181.00 | 156.50 | 26.00 | 8,229.50 |
| Per family | 19.29 | 75.10 | 21.80 | 15.08 | 3.41 | 1.86 | 31.70 |
| Per person | 4.79 | 17.80 | 4.23 | 3.35 | 0.89 | 0.45 | 7.66 |
| Per person sick | 7.64 | 27.20 | 6.90 | 5.66 | 6.27 | 2.17 | 14.05 |

* Labor loss is given for the wage-earning members of a family; casual labor is not included. The wage base is $4 a day.

Table 2. Malaria index, Anderson, California, June 1919

| | Blood smears | | | Histories | | | Number taking quinine |
|---|---|---|---|---|---|---|---|
| | *Neg.* | *Pos.* | *Per cent pos.* | *Neg.* | *Pos.* | *Per cent pos.* | |
| Total examined | 90 | 29 | *25.2* | 33 | 86 | *72.2* | 53 |
| Adults | 62 | 16 | *20.6* | 28 | 50 | *64.1* | 40 |
| 10–15 years | 18 | 10 | *35.7* | 3 | 25 | *80.3* | 10 |
| Under 10 years | 10 | 3 | *23.0* | 2 | 11 | *84.6* | 3 |

well the figures obtained by Gray. It is interesting in this connection to note a history rate of from two to three times the parasite index rate.

### Labor losses

Loss of working time is an important item in estimating the economic damage by mosquitoes, particularly in malarial areas. Figures for this item in our study in a California district are included in Table 1. By arrangement with employers, records of absence on account of malaria can usually be obtained, but in some cases only a house-to-house canvass will furnish the necessary data.

In studying the effect of malaria on tenant labor in Louisiana, the United States Department of Agriculture found a lost time of 1066 days in 74 families from May to October, 1913. Cotton mills in North Carolina have reported from 40 per cent to 60 per cent loss in efficiency in mill hands during the four months of high malaria incidence. The hospital records of railroads[9, 10] in southeastern United States indicate that about one-third of the hospital cases are due to malaria, a considerable part of this being found in the construction and maintenance gangs which may be temporarily stationed, with little protection, in areas of considerable *Anopheles* prevalence.

On large construction work executed in potentially malarial areas contractors today will usually make considerable effort to prevent malaria among their workmen, for a reasonable labor efficiency is essential to the economic prosecution of the work.

The experience of the United Fruit Company in Central America has been particularly impressive. Their reports indicate that earnings of laborers per man-month have been increased about one-third during a three-year program of malaria control and camp sanitation.

Labor losses among casual laborers are not easily ascertained under rural conditions, since casual farm labor shifts rapidly from place to place according to the crops. As casual laborers are frequently not housed at all, or housed in dwellings poorly protected against mosquitoes, they are exposed freely to infection, and usually contract malaria, or are reinfected, within a short time after entering a malarial region. Estimates of this loss could be obtained if each employer of casual labor were asked at the beginning of a season to keep a record of the number of man-days lost on account of malaria. If a record is also kept of the total man-days of such labor, a percentage of lost time, as well as the total lost time, could be obtained.

In areas where salt-marsh mosquitoes are abundant, all forms of outdoor labor, both agricultural and industrial, are rendered less efficient because of time lost in combating swarms of biting insects. One company, for example, in making time studies on outside welding operations, reported that approximately thirty per cent of time was lost where mosquitoes were especially prevalent.

The presence of night-biting domestic species (for example, *Culex pipiens molestus*), if numerous, will have some effect on labor efficiency by causing loss of sleep. The amount of such loss in labor efficiency is not determinable, but may be appreciable.

### Property losses

Depreciation of property values, in terms of money, probably exceeds all other losses combined due to mosquitoes or mosquito-transmitted disease. Its estimation is difficult, and can at best be only an approximation based on the judgment of men particularly well informed on local real estate values. It may run from only a small percentage in slightly affected regions, to fifty per cent or perhaps even more in severely affected areas. In making estimates, it would be advisable to separate urban from rural areas, as the percentage depreciation may be rather different in the two types of area. The depreciation will be the present fair sale price of property subtracted from the probable normal price of property if mosquitoes and mosquito-borne disease are eliminated.

A very illuminating illustration[11] of the benefits of mosquito control was given by R. F. Engle, president of the Ocean County (New Jersey) Mosquito Extermination Commission. He showed that assessed valuations of property in New Jersey, in the fifteen-year period from 1916 to 1930, increased by roughly five hundred and fifty-five million dollars more in the areas where mosquito control work was carried out, than it increased in unprotected areas. Such an illustration is at least highly suggestive even if a careful analysis of his figures should prove them to be not strictly comparable.

Continued malaria, especially malignant tertian (*aestivo-autumnal*) malaria, will cause some residents in malarial regions to sell out and remove to a non-malarial region. Sales of property under such conditions are almost invariably made at a loss of ten to fifty per cent of the purchase price of the property.

People who might otherwise purchase land for homes, farms, or industry will be to some extent deterred from doing so by the presence of malaria, or by the excessive prevalence of mosquitoes, especially the salt-marsh varieties. Local real estate agents can usually give a rough estimate of the amount of commissions on possible sales lost.

Estimates of lost rental on vacant property can be readily made in any region. How much of such vacancy is an excess above a normal vacancy in a healthy community of a similar type can be estimated, and the difference charged to malarial economic loss. In addition, rentals themselves are depressed on account of malaria.

### Loss of crops

Losses due to inability to handle perishable crops at the proper time are not readily ascertained, except by actual investigation of specific cases. In general, the loss is indirect, in that it is necessary to hire additional men to handle the crop so as to avoid the loss. It is probably a significant item of economic loss, but difficult to estimate.

### Summer removals

In intensely malarial or mosquito-ridden communities, families which can do so will frequently remove from the district during the worst malarial or mosquito-infested months. Such removals represent an expense to the family and an economic loss to the community. It can be ascertained on detailed inquiry, but cannot readily be estimated.

### Summer resorts, golf clubs, etc.

Most people on pleasure trips and vacations will leave hotels, beaches, and summer camps, if mosquitoes are numerous, and they will warn others about the discomfort of such places. This represents a cash loss to summer business, which can be measured fairly accurately. We have seen personally, or had brought to our attention by reliable observers, numerous illustrations of such losses, and present here two cases.

Noble M. Stover, superintendent of the Three-Cities Mosquito Abatement District, San Mateo County, California, during a visit in the state of Washington in the summer of 1930, gave mosquito abatement advice to a hotel where he had spent a bad night battling the pests. A brief inspection in the vicinity of the hotel disclosed in an adjacent "pee-wee" golf course several ornamental ponds prolifically breeding mosquito larvae and pupae. Several months later the manager of the hotel in a letter of thanks advised Mr. Stover that the mosquitoes had disappeared entirely after oiling the ponds; and that the hotel, which had been only half occupied and was on the verge of bankruptcy, had since greatly increased its occupancy. For the expenditure of a few gallons of kerosene, a half-million-dollar enterprise had been saved from failure.

The other illustration came under our personal observation in 1933. Byron Hot Springs, a well-known health resort in California, was suffering from a pest of mosquitoes, and a serious loss of revenue in consequence. An inquiry addressed to the University of California resulted in our sending an experienced man to the resort to abate the mosquitoes. He found[12] that the excess water from the various springs formed a marsh which was most prolific in its output of *Culex pipiens molestus;* in addition, there were numerous containers of water about the premises contributing their quota of mosquitoes. The marsh was drained and the surplus water conducted in a ditch to an alkali flat on which the salt content of any standing water would be too high to permit mosquito breeding. Residual water was oiled until it dried up. Permanent ponds were stocked with fish (*Gambusia affinis*), and the water containers about the place either emptied or treated with larvicide. A few hundred dollars spent on drainage and oiling promptly stopped a loss to the proprietors, and in addition contributed greatly to the comfort of the patients at the resort.

These two illustrations could be multiplied almost indefinitely with examples ranging from a very minor economic loss to a total loss on a considerable investment.

There is no question that outdoor amusements also suffer material losses from invasions of mosquitoes. As an example, the receipts of the Oakland (California) municipal golf links were markedly reduced in the summer of 1929, as a result of a severe infestation of salt-marsh mosquitoes (*Aedes dorsalis*). Table 3 gives the monthly receipts of the links for the years 1928–31. It will be observed that the receipts increased in 1928 to 1930, and began to decrease in 1931 as a result of the depression. However, the months of June, July, and August (the months of greatest prevalence of *Aedes dorsalis* in this region) show a distinct picture of reduced attendance. In 1928 and in 1930 there were average crops of *Aedes dorsalis*, but 1929 was a year of great output. Judging from the hatch of undrained marshes in the southern part of Alameda County, 1931 was also a year of large output, but by that time the mosquito abatement dis-

TABLE 3. Monthly receipts of Oakland, California, municipal golf course in 1929, a year of great mosquito prevalence, compared with receipts of preceding and subsequent years

| Month | 1928 | 1929 | 1930 | 1931 |
|---|---|---|---|---|
| January | $ 2,221.50 | $ 2,254.75 | $ 2,688.00 | $ 3,851.50 |
| February | 2,653.75 | 3,166.75 | 3,397.50 | 3,735.75 |
| March | 2,607.75 | 2,570.25 | 3,839.00 | 4,540.75 |
| April | 2,659.75 | 3,294.50 | 3,428.50 | 4,311.75 |
| May | 3,974.00 | 5,051.50 | 4,351.25 | 3,209.00 |
| June | 3,225.00 | 3,865.50 | 5,002.75 | 4,925.75 |
| July | 4,041.50 | 2,830.00 | 5,151.50 | 4,615.75 |
| August | 4,203.75 | 2,923.25 | 4,983.50 | 5,617.00 |
| September | 3,435.65 | 3,692.00 | 5,558.50 | 4,875.75 |
| October | 2,543.50 | 3,631.25 | 4,130.75 | 3,745.50 |
| November | 2,033.50 | 2,603.75 | 2,804.00 | 3,062.25 |
| December | 2,269.75 | 2,980.25 | 3,910.25 | 1,542.25 |
| Total | $35,869.40 | $38,863.75 | $49,245.50 | $48,733.00 |
| June, July, August | $11,680.90 | $ 9,445.25 | $15,693.50 | $15,108.50 |

trict had succeeded in draining the marshes affecting Oakland. The district did not begin drainage operations until September 1930, too late to have any effect on the mosquito output for that year. Another item of interest is the small receipts in March 1929. March is the month of migration of *Aedes squamiger*, and a particularly severe flight occurred in March 1929, adversely affecting the attendance in the latter half of the month.

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# III

## LAWS AND AGENCIES FOR MOSQUITO ABATEMENT

If mosquito control is to be successful, some organization must be made responsible and be equipped with the necessary authority and means. It is possible to use existing political organizations for this purpose, but the practical difficulties are at times considerable, as few existing political entities match in their boundaries the mosquito-infested areas which should be treated as units. For that reason different types of organizations have been established by laws in various states.

New Jersey was faced with a practically state-wide mosquito problem, which required coordination as a whole for effective control. The state could have solved the problem by establishing a state department of mosquito abatement, the cost of which would have been defrayed by a state-wide tax. Instead, New Jersey elected to make it compulsory for each county to establish a mosquito abatement organization, and to defray the costs by county taxation. Coordination was provided by making an appointive state official an ex-officio member of the commission in each county, with control over the kind and amount of work to be done.

In California, in contrast, the mosquito problem is localized in certain areas and is not state-wide, therefore the organization of such districts is optional. The districts do not necessarily correspond with counties as units; they may include a part of a county or contiguous parts of two or more counties. There is no compulsory state coordination and control and as a result many areas in which mosquitoes are a considerable nuisance have no organization for abatement, to their own detriment and the annoyance of adjacent areas; also some districts have been organized which are so small and which have such restricted funds as to be rather ineffective in their operations.

### *SPECIAL DISTRICT AND COUNTY AGENCIES*

The general types of mosquito abatement agencies organized along county and district lines can be illustrated by brief descriptions of the enabling acts in several states.

THE NEW JERSEY LAW

New Jersey, so far as we are informed, was the first of the United States to set up a separate and distinct governmental unit for the control of mosquitoes. As early as 1904 (Chapter 119, Laws of 1904), New Jersey decreed that water in which mosquito larvae breed was a public nuisance abatable by the local boards of health, and that if abatement was not performed by the property owner upon due notice, then the abatement could be performed by the local board of health, and the cost made recoverable by an action of debt against the offending owner.

This procedure, following the old accepted legal formula for the abatement of nuisances, overlooked entirely the time element which is so important in mosquito control. Other governmental mechanisms and methods had to be devised which would be more workable and efficient than procedures under the public nuisance formula. By Chapter 134, Laws of 1906, New Jersey made it the duty of the director of the state experiment station, through an assistant appointed by him, to examine all the salt-marsh areas within the state, to indicate on a map the mosquito breeding marshes, and to prepare an estimate of the cost of abatement. It was also made his duty, on request of any local board of health, to locate and report upon, with a map, fresh-water mosquito breeding places within the jurisdiction of the local board. The method of abatement still continued under the nuisance formula, except that provision was made that if, in the case of salt-marsh mosquito breeding, the owner did not comply on due notice, or if it was deemed inexpedient by the local board of health to depend upon compliance by the property owner, then the cost of abatement could be defrayed by the municipality or county if local funds were available, or if not available application for funds could be made to the director of the state experiment station.

If it appeared to the director that it was in the public interest to do so, he could, out of the money appropriated annually by the state legislature for the purpose (not exceeding an aggregate total for all years of $350,000), proceed to abate mosquito breeding in infested areas under the direct supervision of some person appointed for the purpose by the local board of health. Provision was made also for the state and the local government unit jointly to defray the cost of abatement.

As procedure under the 1906 act proved to be too cumbersome, a law was passed (Chapter 104, Laws of 1912, later amended in various ways) providing for the organization of county mosquito extermination commissions. It was made the duty of the state supreme court justice presiding over the courts in any county to appoint six persons as commissioners who serve without salary. The director of the state experiment station was made ex-officio a member of each county mosquito extermination commission, and later (1915) the state director of health was made an ex-officio member. The commissions were given power to employ assistants and to take necessary steps to eliminate mosquito breeding places within their county.

By Chapter 142, Laws of 1927, the scope of the law was further modified to abate fresh-water as well as salt-marsh mosquito breeding; and the director of the state experiment station was given power on his own initiative to institute and defray the cost of abatement of mosquito breeding places found within municipalities. The $350,000 limit of expenditures was removed; and the mosquito extermination commissions were given the same powers as health officials, in respect to mosquito abatement. Two excellent provisions were added to the 1927 amendment. In one the director of the state experiment station is required to carry on investigations into life-histories, habits, and methods of control of mosquitoes; in the other he is directed to spread information as to methods of mosquito abatement among the people of the state.

The county commissions yearly present to the director of the state experiment station a detailed estimate of the amount of money required for mosquito abatement work in their counties for the ensuing calendar year, together with a plan of work and the methods to be used. The director of the state experiment station can approve, modify, or alter these estimates, and when approved by him it becomes mandatory upon the board of "chosen freeholders" of each county to include the approved amount of money in the annual tax levy. Certain limitations upon the tax are set, as follows:

| *Total assessed valuation of county* | *Tax rate per $100 of assessed valuation* |
|---|---|
| Less than $25,000,000 | 10.0 cents |
| $25,000,000 to $50,000,000 | 5.0 cents |
| Over $50,000,000 | 2.5 cents |

The money so raised by taxation is paid by the board of freeholders to the extermination commission from time to time as required, upon written demand of the commission.

Table 4 (page 30) gives data as to budget appropriations, gross and unit, of the New Jersey districts in 1932.

THE CALIFORNIA LAW

Under the California act (adopted in 1915, extensively amended in 1937 and 1941, and affected by the Districts Investigation Act of 1933) any contiguous territory, within one or more counties, may be organized upon a petition, signed by resident voters in the proposed district equal in number to at least ten per cent of the votes for governor at the last election.

After filing the petition, a report must be prepared by a competent person, showing the public necessity of the proposed district, estimating its probable annual costs, and setting forth the name and address of each taxpayer in the proposed district, his assessed valuation, and his probable tax. A notice of the time and place of hearing on the petition must then be mailed to each taxpayer, in addition to a published notice.

The cost of these preliminaries is covered by a bond executed by the proponents of the district. If the district is formed, the organization costs are paid by the Board of Supervisors; if it fails, they are paid by the bondsmen.

Upon a public hearing, the board of supervisors of the county in which the proposed district is situated then determines whether the public interest requires the formation of a mosquito abatement district, and if it so determines, it by resolution organizes the district, fixes its boundaries, and determines its name.

The act provides for the annexation of contiguous territory upon a ten per cent petition and a hearing before the board of trustees of the district. The procedure is simple and requires no review or control by any other public body, except that if there be any incorporated municipality or any part of a municipality within the proposed district, the city council thereof must by resolution approve the inclusion within the district.

The district when formed is governed by a board of trustees. If there are no incorporated municipalities within the district, the county

Table 4. New Jersey Mosquito Extermination Commissions' appropriations for 1932

| County | Year established | Population 1930 | Area in square miles | Assessed valuation 1932 | Appropriation 1932 | Cost per person | Cost per square mile | Cost per $100 of assessed valuation |
|---|---|---|---|---|---|---|---|---|
| Atlantic | 1913 | 450,000 | 569 | $ 343,815,140 | $ 20,000 | $.044 | $ 35 | $.0058 |
| Bergen | 1914 | 405,000 | 239 | 502,281,687 | 45,000 | .111 | 188 | .009 |
| Cape May | 1916 | 500,000 | 193 | 99,321,046 | 10,000 | .020 | 52 | .01 |
| Essex | 1912 | 834,400 | 129 | 1,637,680,964 | 78,500 | .094 | 61 | .0048 |
| Hudson | 1913 | 707,933 | 40 | 1,247,479,389 | 85,000 | .120 | 2,120 | .0068 |
| Middlesex | 1914 | 212,000 | 264 | 220,646,149 | 20,000 | .094 | 76 | .0091 |
| Monmouth | 1915 | 175,000 | 538 | 250,000,000 | 15,000 | .086 | 28 | .006 |
| Morris | 1918 | 110,381 | 410 | 118,419,692 | 25,000 | .226 | 67 | .023 |
| Ocean | 1916 | 52,000 | 638 | 52,407,672 | 7,500 | .144 | 12 | .014 |
| Passaic | 1913 | 303,482 | 191 | 425,285,846 | 16,000 | .053 | 84 | .0038 |
| Sussex | 1930 | 27,830 | 529 | 33,867,676 | 2,000 | .072 | 4 | .0059 |
| Union | 1912 | 315,000 | 104 | 493,001,034 | 66,000 | .210 | 634 | .0134 |
| Total or average | | 4,093,026 | 3,844 | $5,426,206,295 | $390,000 | $.095 | $ 101 | $.0072 |

Table 5. California mosquito abatement districts' appropriation for 1932–33

| District | Year established | Population 1930 | Area in square miles | Assessed valuation 1932 | Appropriation 1932–33 | Cost per person | Cost per square mile | Cost per $100 of assessed valuation |
|---|---|---|---|---|---|---|---|---|
| Alameda | 1930 | 457,482 | 320 | $402,441,830 | $ 31,117 | $ .068 | $ 97 | $.008 |
| Anderson | 1919 | 1,300 | 8 | 414,035 | 414 | .318 | 53 | .10 |
| Clear Creek | 1920 | 400 | 15 | 281,930 | 281 | .703 | 19 | .10 |
| Compton | 1927 | – | – | 10,297,490 | 2,059 | – | – | .02 |
| Contra Costa | 1926 | – | 55 | 27,243,800 | 8,173 | – | 15 | .03 |
| Cottonwood | 1919 | 450 | 3½ | 201,960 | 201 | .447 | 58 | .10 |
| Delta | 1922 | 10,000 | 16 | 5,233,089 | 2,616 | .262 | 163 | .05 |
| Dr. Morris | 1916 | 32,500 | 48 | 26,266,245 | 26,266 | .818 | 547 | .10 |
| Durham | 1918 | 1,200 | 60 | 2,195,025 | 1,317 | 1.100 | 22 | .06 |
| Los Molinos | 1917 | 2,500 | 32 | 2,572,920 | 2,573 | 1.030 | 80 | .10 |
| Marin | 1915 | – | 158 | 23,673,740 | 11,837 | – | 75 | .05 |
| Matadero | 1917 | 27,000 | 52 | 15,919,450 | 19,103 | .683 | 368 | .12 |
| Merced | 1923 | 8,100 | 17 | 4,612,500 | 2,306 | .284 | 135 | .05 |
| Napa | 1925 | 23,541 | 782 | 21,275,148 | 4,255 | .181 | 6 | .02 |
| Oroville | 1916 | 8,000 | 12 | 3,743,940 | 2,246 | .280 | 184 | .06 |
| Pine Grove | 1931 | 800 | 210 | 586,560 | 586 | .733 | 3 | .10 |
| Pulgas | 1916 | 20,412 | 100 | 14,201,835 | 8,947 | .438 | 90 | .063 |
| Redding | 1919 | 4,200 | 4 | 2,264,630 | 2,264 | .540 | 566 | .10 |
| Solano | 1930 | 40,834 | 850 | 32,120,738 | 12,848 | .315 | 15 | .04 |
| Sonoma | 1917 | – | 210 | 3,287,500 | 1,644 | – | 8 | .05 |
| Three Cities | 1915 | 24,806 | 33 | 19,400,175 | 6,790 | .274 | 206 | .035 |
| West Side | 1931 | – | 433 | 60,958,050 | 18,287 | – | 41 | .03 |
| Total or average | | – | – | $630,091,590 | $155,135 | $ .188 | $ 48 | $.0246 |

Note. A dash means that the figure was not available.

board of supervisors appoints five trustees, who serve for two-year terms. If any incorporated municipalities are within the district, the city council of each appoints one trustee, and the board of supervisors any remainder to make up five; if there are four or more municipalities, the board of supervisors appoints only one.

The trustees serve without salary, though any expenses incurred on account of official business of the district are refunded to them. The secretary of the board may be paid such compensation as is determined by the board, but few districts have paid their secretaries. This requirement that the trustees serve without salary has been one of the best features of the act, as it has removed any temptation to mere politicians, and has attracted a high type of citizen who will serve his community out of public spirit.

The board of trustees manages the affairs of the district, employs the personnel, and fixes the annual budget. It sends the budget to the board of supervisors, which must levy a special tax (not exceeding fifteen cents on each one hundred dollars of assessed valuation in the district) sufficient to raise the amount set in the budget. The money so raised by taxation is collected by the county tax collector with the general county taxes, and by him paid to the county treasurer, who holds it in a trust fund, from which expenditures of the district are defrayed upon drafts drawn by the board of trustees of the district.

In addition to the twenty-five districts organized under the Mosquito Abatement District Act, two districts for the abatement of mosquitoes have been organized under the Pest Abatement District Act of 1937. The procedure of organization is similar but is less elaborate, and the organization costs are much less to the proponents, in that the report and bond are not required. The petitioners for the district must designate the particular pest to be abated. The trustees of the district are under closer financial control by the board of supervisors than are the trustees of the mosquito abatement districts.

Table 5 gives the budget appropriations, gross and unit, of the California districts for 1932–33. A comparison of the operating costs of the New Jersey districts with those of the California districts (Tables 4 and 5) discloses several interesting facts of general application. As might be expected, districts in different regions exhibit wide variations in unit costs and in tax rates. The New Jersey districts make a better showing from a tax rate viewpoint than the California districts, due to differing conditions. The New Jersey districts have a much larger rate base of valuation; only two California districts exceed the lowest valuation of any New Jersey district. Presumably, also, the New Jersey districts have been established longer, and have long since completed most of the large initial expenses of marsh drainage which many of the smaller and younger California districts have not yet done. On a population basis, as would be expected from the considerably denser population in New Jersey, the New Jersey districts show a lower per capita cost, and the California districts a lower cost per square mile of area. These variations in unit costs and tax rates need to be interpreted in the light of the local conditions in each district, and may not be used as guides to probable expenditures elsewhere without such interpretation.

### Critical provisions of state laws

The New Jersey law has worked well over the thirty-two years it has been extant. Part of the reason for its success has undoubtedly been the fact that all the districts have been subject to centralized direction and skilled technical advice through the director of the state experiment station. This judicious combination of local autonomy with state coordination and research has made for efficient and skillful management and strong local interest, without acquiring the deadening effect of bureaucratic centralization. Destructive political interference has also been minimized, though it is not humanly possible, regardless of the form of organization, entirely to avoid political influence upon any governmental body in a democracy. The politicians overlook no jobs, no matter how small, nor how devious the ways required to place their adherents in them.

The mechanism of tax levying adopted in New Jersey may in some other states rest on doubtful legal foundations, in that the tax is a mandatory levy, proposed by a non-elective commission, approved by an appointive administrative official, and presented to the elective tax-levying body with no provision for amendment or rejection by the elective board which actually imposes the tax. A somewhat similar provision occurs in the California act, under which the boards of trustees of the districts (which are appointive and not elective) propose annually to the board of supervisors a sum of money required for district purposes during the ensuing fiscal year, which sum the board of supervisors is required to raise by a special tax levy, within a maximum limit of fifteen cents on each one hundred dollars of assessed valuation.

Such exercise of the taxing power by appointive and non-elected boards or commissions has been construed in various ways by various courts. Possibly the decision as to constitutionality will depend on whether the state was organized first, all local powers being derived from the state, or whether the state was originally a confederation of smaller local units. As it concerns mosquito abatement districts specifically, there do not appear to be any judicial decisions extant. The numerous decisions concerning special improvement districts, such as drainage districts, irrigation districts, water districts, fire districts, and the like, seem in general to recognize the power of the legislature to delegate the taxing power to these districts in such manner as appears expedient and desirable, provided no provision of the state constitution is violated.

The purpose of making the tax requests of the mosquito abatement districts mandatory upon the local taxing authority undoubtedly has been to minimize political pressure upon the trustees of the districts. Whoever determines the amount of money to be spent also can determine who shall be employed, and the nature and extent of the work done. If the boards of supervisors controlled the amount of the tax, they would have control over the districts, without responsibility, and leave to the district trustees merely responsibility shorn of actual power.

Where it appears to be desirable to govern mosquito abatement districts by appointive, non-political boards of trustees with mandatory taxing powers, the law should be most carefully drawn in order that there may be no legal difficulty over the exercise of such power. The best legal counsel should be consulted in preparing the draft of the legislative act.

This provision of a mandatory tax proposed by a non-elective board, in spite of criticism in some instances, has worked well in practice. It has not resulted in excessive taxation, and the appointive boards appear to have been at least as responsive to public demands for restraint in taxation as any elective agencies of government.

The New Jersey act sets forth the powers of the mosquito extermination commissions as follows:

Each such commission shall have the power to eliminate all breeding places of mosquitoes within the county wherein it is appointed, and to do and perform all acts and to carry out all plans which in their opinion and judgment may be necessary and proper for the elimination of breeding places of mosquitoes, or which may tend to exterminate mosquitoes within said county.

By the powers conferred under the California act (1941), the district board may:

1. Take all necessary or proper steps for the extermination of mosquitoes, flies, or other insects either in the district or in territory not in the district but so situated with respect to the district that mosquitoes, flies, or other insects from such territory migrate into the district.
2. Subject to the paramount control of the county or city in which they exist, abate as nuisances all stagnant pools of water and other breeding places for mosquitoes, flies, or other insects either in the district or in territory not in the district but so situated with respect to the district that mosquitoes, flies, or other insects from such territory migrate into the district.
3. Purchase such supplies and materials, employ such personnel and contract for such services as may be necessary or proper in furtherance of the objects of this chapter.
4. If necessary and proper, in the furtherance of the objects of this chapter, build, construct, repair, and maintain necessary dikes, levees, cuts, canals, or ditches upon any land, and acquire by purchase, condemnation, or by other lawful means, in the name of the district, any lands, rights of way, easements, property, or material necessary for any of those purposes.
5. Make contracts to indemnify or compensate any owner of land or other property for any injury or damage necessarily caused by the use or taking of property for dikes, levees, cuts, canals, or ditches.
6. Enter upon without hindrance any lands, within or without the district, for the purpose of inspection to ascertain whether breeding places of mosquitoes, flies, or other insects exist upon such lands; or to abate public nuisances in accordance with this article; or to ascertain if notices to abate the breeding of mosquitoes, flies, or other insects upon such lands have been complied with; or to treat with oil or other larvicidal material any breeding places of mosquitoes, flies, or other insects upon such lands.
7. Sell or lease any land, rights of way, easements, property, or material acquired by the district.
8. Do any and all things necessary or incident to the powers granted by, and to carry out the objects specified in, this chapter.

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to certain specified duties and powers, the districts have the duty and power to perform such acts as are necessary and incident to the requirements of mosquito abatement. Such language is vague and indefinite, and may be interpreted narrowly or broadly according to the disposition of attorneys or judges. One essential power is omitted from the New Jersey act which should be specifically included in every mosquito abatement law. This is the power of duly appointed and authorized employees of mosquito abatement districts to inspect at reasonable times, without interference or obstruction, any premises within the district for the purpose of ascertaining whether mosquito breeding exists upon any property. As this power of inspection is absolutely fundamental to successful mosquito control, it should be included in any mosquito abatement act in specific terms.

Another power appears to be highly desirable, namely permission to perform mosquito control work outside the district boundaries on lands breeding mosquitoes which may migrate into the district. Many districts have to do work outside their boundaries in order to protect their own inhabitants adequately; in some cases this is strictly illegal, and if done must be performed through subterfuge or camouflage.

A further desirable provision, added to the California law in 1941, makes it a misdemeanor for anyone to damage or tamper with any works for mosquito abatement, or to interfere with any work of the districts.

### The Utah law

The Utah mosquito abatement law (Chapter 90, Laws of Utah 1923, amended 1931) is one of the best and simplest state laws on this subject. It follows the general outline of the California law, but with less mere verbiage. A 1939 amendment permits the Utah districts to perform control work outside district boundaries when necessary to protect the people within the district.

### The Illinois law

The Illinois mosquito abatement district act (adopted in 1927) provides for the organization of mosquito abatement districts upon a petition of five per cent of the legal voters within the proposed district. The petition is addressed to the judge of the county court, who upon a hearing held within twenty days after the petition is filed with the county clerk determines whether the public health and welfare require the formation of such a district. He also determines the boundaries of the proposed district.

If the decision of the county judge is favorable, he calls an election upon the question, to be held within thirty days after the entry of his decision upon the records of the county court. If a majority of the qualified voters present and voting vote affirmatively, the district becomes organized as a body corporate and politic. Within ten days after such organization the county judge appoints a board of trustees of the district, consisting of five members, of whom one is elected by the board of trustees as its treasurer and handles the district funds. There is apparently no provision for bonding the treasurer.

The Illinois act has the peculiar feature of requiring, for organization of a district, not only a public hearing before the county judge and his determination of the public necessity of such a district, but also an election. If an election is to be held, the hearing before the judge would seem to be legally superfluous. There is no reason that judges' findings concerning such things as necessity and convenience in matters of public health and welfare should be "conclusive and not subject to review." Under the Illinois act venal judges could use the mosquito abatement districts, through control of appointments, to strengthen their political organization. Such appointments would have no relation to economy or efficiency in the actual abatement of mosquitoes.

### The Rhode Island Law

The 1934 General Assembly of Rhode Island passed an act by which any local community may call to the attention of the state commissioner of agriculture the presence of mosquitoes in numbers sufficient to constitute a public nuisance. Thereupon the commissioner investigates and prepares plans for abatement, which plans are presented to the governing body of the local community for approval or modification. When finally approved by the commissioner and the local governing body, the commissioner provides trained engineering and entomological supervision, and the local community the labor, equipment of one cent on each dollar of assessed valuation. State expenditure is limited to twenty per cent of the total cost.

In 1942, owing to labor shortage and other factors, the local communities declined to continue responsibility and funds for maintenance, the legislature did not provide maintenance appropriations, and therefore maintenance on drainage projects practically ceased, with resulting mosquito annoyance.[1]

### The Mississippi law

The Mississippi mosquito abatement law became effective in April 1928, and was limited to the abatement of mosquito breeding in the counties along the Gulf of Mexico and the Mississippi River. It provides for the usual board or commission, of three members, with the state health officer an ex-officio member. Appointment of the commission is made by the county board of supervisors, and is permissive and not mandatory. Two or more counties may combine to employ the same personnel to carry on the work. Financial control is in the hands of the county supervisors who may appropriate annually not more than fifteen cents on each $100 of assessed valuation in counties having an assessed valuation of less than $20,000,000; or not more than ten cents on each $100 in counties having more than $20,000,000 assessed valuation.

Each commission annually submits to the state health officer and the board of supervisors a plan of operations and estimate of cost.

The law supplements the control measures against *Anopheles* mosquitoes (which are presumed to be undertaken by the county health departments in malarial areas) and is directed primarily against non-vector pest mosquitoes.

### The Florida law

The Florida law provides for the county as the unit for mosquito abatement districts (called "anti-mosquito districts" in Chapter 13570, Acts of 1929). The districts are organized on an election called by petition of ten per cent of the resident freeholders of the county. In counties having more than 65,000 population, the board of county commissioners acts as the board of the district; in counties of less than 65,000 population, a separate board of three citizens may be established by election. The only qualification for these three commissioners, as stated in the act, is that they be "discreet."

These anti-mosquito commissioners serve without compensation, but their actual expenses incurred in the conduct of their work are defrayed by the district. The state board of health has direct control over the work of the various districts through the power of approval of plans in each calendar year; and a representative of the board is an ex-officio member of each commission. By law the district expenditures are limited in counties of less than 65,000 population to not less than $10,000 nor more than $20,000, and in counties of more than 65,000 population to not less than $20,000 nor more than $50,000, as determined by the district commissioners. Taxes are levied by the tax assessor and state comptroller, and when paid to the county treasurer are remitted by him to the commissioners of the district. The designation of maximum and minimum fixed sums for taxation is a variance from the usual procedure of setting a maximum tax rate.

The district boards appear to have about the usual powers granted to such boards in other states. They are given, however, two powers which we do not believe should be granted. One is the power to make rules and regulations not inconsistent with law which may be necessary in their opinion for the proper enforcement of the act, subject to approval by the state board of health. We believe that administrative local boards of this type should not be given quasi-legislative powers. If rules and regulations are required supplementary to the anti-mosquito district act, they should be of uniform and general application, and promulgated by the state board of health. The other questionable power is the right to borrow money in anticipation of tax receipts. We believe that such power is so frequently abused that it is not in the public interest to permit governmental bodies to expend or contract for the expenditure of money unless the cash be presently in hand to defray such expenses, except upon bond issues duly voted by the electorate.

### The New York Law

Mosquito extermination commissions may be appointed in any county in New York State (not including New York City). Upon petition of 200 residents of the county, it is the duty of the county judge to convene an appointing board consisting of the county clerk, the county comptroller, and himself. In counties containing four or more towns, however, the board of supervisors is the appointing board. There is no provision for a hearing on public convenience or necessity, nor for an election.

The formation of the commission is mandatory, and in either case the judge or the board appoints a county extermination commission consisting of four resident taxpayers of the county. To these four members are added the chairman of the board of supervisors and an additional member appointed by the state commissioner of health. The members of the commission serve without salary, but their actual official expenses are defrayed. The terms of office are for four years. The commission may appoint a secretary at a salary fixed by it with the approval of the county board of supervisors; and such clerks, assistants, inspectors, and day laborers as may be necessary, at compensations fixed by the board of supervisors.

The commission is directed to use every feasible and practicable means for the extermination of mosquitoes within the county, and for this purpose has the right to enter upon any lands in the county to drain or treat them, and is authorized to perform all other acts necessary and proper for the elimination of mosquito breeding places, provided that such measures shall not be injurious to wild life. Before entering upon any land, however, the commission must publish at least once a year, in a newspaper in the county, a general description of the lands to be worked upon. Property owners are given the right of protest, and a public hearing thereon, but upon such hearing the decision of the commission is final, subject to claims for damage subsequently adjudicated in court.

The commission annually on September first submits to the board of supervisors and to the state commissioner of health a detailed estimate of money required for the ensuing year and a plan of the work to be done, the methods to be employed, and a description of the lands, with the names of the owners, upon which the work is to be done. The board of supervisors has power to amend or alter these estimates, plans, and methods, and when it finally approves them it includes in the county tax the approved sum for the use of the commission, provided that in counties of less than forty million dollars assessed valuation the tax rate shall not exceed ten cents on each $100, and in counties having more than forty million dollars assessed valuation, the tax shall not exceed three and three-fourths cents per $100. The tax receipts are paid by the county treasurer to the treasurer of the commission, on the commission's requisition.

The commission is required to submit an annual report of its work to the state commissioner of health and to the board of supervisors.

The provisions of the act by which it is necessary to list and publish all properties upon which work is proposed to be done during the ensuing year, with the names of the owners and descriptions of the work to be done, appear to us to be an unnecessary and burdensome procedure resulting in excessive overhead cost. One of the things we have learned from experience is the comparative unpredictability of mosquito breeding (especially of *Culex pipiens*), and the folly of too rigid a plan of procedure. Such a provision lacks the necessary flexibility for effective mosquito abatement, and in our opinion would tend to produce a legal formalism which would suppress initiative, adaptability, and resourcefulness on the part of the organization.

The New York act differs fundamentally from the laws in other states, in that the county board of supervisors is for all practical purposes absolutely supreme in power over expenditures, personnel, and procedure. In actual fact the county mosquito extermination commissions have no *real* authority. Under the conditions laid down by the New York law we see no reason whatsoever for the existence of such commissions. All procedures would be far simpler if the commissions were eliminated and the nominal powers now granted to the commissions were given back to the board of supervisors, who could then carry on the work through a superintendent and subordinate staff as direct employees of the boards of supervisors. A provision could be included by which the state commissioner of health would have power to review all plans, procedures, and budgets, so as to assure competent technical supervision of all work.

## *COUNTIES AS MOSQUITO ABATEMENT AGENCIES*

Theoretically, there is no necessity for a separate and distinct governmental unit created for the sole or principal purpose of mosquito abatement. In recent years such special agencies or districts have been criticized by persons unacquainted with past conditions, as being unnecessary duplications in government. They may be duplications, but apparently they are in practice the only means by which results can be obtained under the existing political organization.

The great practical difficulty in getting county officials to act can only be appreciated by those who were active in mosquito abatement work in its early days in the United States. The ignorance, the resistance to change, the unwillingness to do anything for the public health, at times even the venality of many county officials can hardly be believed unless actually encountered. Exceptions to this statement have occurred, but on the whole this situation today is not very greatly changed.

It should be axiomatic that it is a primary duty of county health departments to carry out effective anti-mosquito measures in every area where a mosquito-transmitted disease is endemic or may become epidemic. Unfortunately, this is by no means the usual case, and in many cases where it now is true it has only been brought about by intervention in one or more forms by the state health departments or by the United States Public Health Service or by the Rockefeller Foundation operating through its International Health Division.

When it comes to the matter of pest mosquito control, without any question of malaria or other mosquito-borne diseases being involved, the county officials are usually even more indifferent. Rural people are accustomed to insect pests, and with them a few mosquitoes more or less are a matter of no great importance. They are inured to a certain amount of discomfort and will merely grumble somewhat if mosquitoes are especially prevalent: seldom will the idea that anything can be done about it cross their minds.

Even if the idea does occur to them, their conservatism, or inertia, is very apt to prevent any effective action. Here again there are numerous exceptions, but when we realize how much of our rural area would be beautiful and desirable if it were not for unnecessary unsanitary conditions (of which mosquito prevalence is only a single item) we cannot but wonder why such backwardness continues under civilized conditions.

Another practical difficulty may occur in counties which have incorporated municipalities within their boundaries, and which maintain separate health departments, one in the county and one in each of the municipalities. In such cases, the municipalities usually exercise exclusive health jurisdiction within their corporate limits, leaving to the county health department practically exclusive jurisdiction in the unincorporated areas. Where there is no unified control and direction, mosquito abatement may be made impossible of successful prosecution. Mosquitoes (especially the salt-marsh varieties) have a complete indifference to political boundary lines, and their migrations cannot be influenced by an ordinance.

There is no reason why the municipalities could not arrange with the county government to take over the abatement of mosquitoes within their boundaries. In some states provision is made, by law, for the joint exercise of common powers by two or more governmental agencies, and valid contracts may be made whereby one agency will perform certain services for several other agencies. In practice, however, this is seldom done. It is possible, also, for two or more counties to cooperate in the control of a joint mosquito problem, but this likewise is seldom done.

Although there may be political difficulties in the way of effective county-wide mosquito abatement by counties which include incorporated municipalities within their boundaries, nevertheless some very good mosquito abatement has been done by counties in their unincorporated areas. In some southern states mosquito abatement work in the rural areas, under the direct supervision of the county, has resulted in marked reduction in prevalence of malaria.

### County health departments as abatement agencies

In the great majority of counties excellent mosquito abatement work could be done if the county health department were properly organized and directed and had on its staff at least one adequately trained sanitary engineer. Too frequently, however, the job of county health officer is held by some physician as a political sinecure; he has no interest in public health, and no specific training for it, and his principal work consists in giving medical treatment to the county indigents, as a side issue to his private medical practice. Sanitary statesmanship cannot be expected from such men.

On the other hand, the county health department headed by a full-time health officer with specific public health training can and frequently does include mosquito abatement work in its program. The limitation here, however, is that such departments are likely to confine their mosquito abatement measures to the species which are vectors of diseases such as malaria and dengue, and to ignore the species which have no demonstrated relation to communicable disease. This is strictly logical and correct so far as the prevention of communicable disease is the primary function of the health department and is the first consideration in its mosquito abatement program. But mosquito damage does not stop with health; it also affects the public welfare, comfort, and economic prosperity. While we recognize the general validity of the precise public health viewpoint that nuisances which have no direct relationship to disease should not be a function of the health department, nevertheless we feel that at least in county health departments this nice distinction may well be abandoned in the interest of the general welfare. No other department of county government is available to handle the mosquito nuisance unless a mosquito abatement district can be organized for the purpose. Furthermore, as very few people can make any distinction between the vector species and non-vector species, any campaign which attempts to abate only the vectors and ignores the non-disease-carrying types may become rather discredited in public opinion because mosquitoes are still prevalent in spite of an anti-mosquito campaign.

There have been, it is true, strange exceptions to the previous statement. For example, we are informed that the Fair Oaks District, in Sacramento County, California, discontinued operations after malaria had been extirpated from the district. The citizens of this district admitted that culicine mosquitoes were still present, but were prepared to endure their presence in preference to raising even the moderate amount of taxes required. When they got rid of endemic malaria they were satisfied. In this case, these people were intelligent enough to distinguish between public health and public comfort, but their standards of comfort were not high.

We are of the opinion that health departments in the future may not be able to ignore the mosquitoes which have heretofore been considered to be merely pests. As previously stated, recent studies have incriminated certain *Aedes* and *Culex* species as vectors of encephalitis. We therefore are compelled to increase our list of vector species of mosquitoes of which health departments must take cognizance, some of which have heretofore been regarded as merely pests.

## *CITIES AS MOSQUITO ABATEMENT AGENCIES*

Municipalities can, and frequently do, successfully abate mosquito breeding within their corporate limits. Where the principal or only mosquito species is *Aedes aegypti* or a similar species of limited flight range, the municipality is a satisfactory unit for mosquito abatement. But where the mosquito problem is in part an invasion of salt-marsh mosquitoes from breeding places some distance outside the municipal limits, the city government is legally handicapped, and some other agency must be invoked.

Municipal health departments are usually better organized and directed than county health departments, especially as regards sanitation, and can as a rule handle local fresh-water breeding, especially with the cooperation of the street or sewer department. In the larger cities special men can be detailed to this work.

It is possible to have the mosquito abatement work performed by municipal departments other than the health department. If there is a separate department of sanitation, as is sometimes the case, mosquito abatement could be carried on by it. The street department might also do the work, but it would seem more logical to place mosquito abatement under the sanitation division of the health department, or the department of sanitation if that is a separate department. The health department possesses the legal authority of inspection of private premises, which is essential to mosquito abatement. The street department authority is limited to public streets, and it is doubtful if such authority could be stretched to cover entry and inspection of private premises.

## *STATE AGENCIES IN MOSQUITO ABATEMENT*

With certain exceptions, mosquito abatement at least in temperate climates is a local problem. The exceptions are not numerous and are restricted principally to areas with migrating species of salt-marsh or flood-water mosquitoes. Mosquito abatement, in its direct application at least, has therefore been commonly a function of local government, rather than a state or national function, and this seems logical. We have heard on several occasions the criticism that mosquito abatement should be state-wide, directed and financed by the state government, but in that opinion we cannot agree, except as it applies to tropical areas where mosquitoes and mosquito-borne diseases are ubiquitous. In states such as New Mexico and Arizona, having extensive arid areas where population is very sparse and where mosquito breeding is confined to river bottoms and irrigated valleys, state-wide mosquito control would be, in our opinion, illogical and uneconomical.

In such very small states as Rhode Island, Delaware, and Connecticut, state-wide mosquito abatement would appear to be logical. Connecticut, for example, has less salt-marsh mosquito breeding area than one California county.

### The connecticut law

Connecticut does not make provision for mosquito abatement districts, but places the actual work under the supervision of the director of the agricultural experiment station. The size of the state is such that the salt-marsh mosquito problem can be handled from one central state office. Local cooperation is provided for in the following manner.

Any township or community may provide funds for marsh drainage, and if this work is done to the satisfaction of the director of the agricultural experiment station and accepted by him, it is thereafter maintained by the state out of an appropriation of $12,500 annually provided for this purpose. In 1934 Connecticut had about 12,000 acres of marsh drained and accepted; about 8000 acres drained but not accepted; and about 5000 acres requiring drainage. Their drainage costs have run from ten to fifteen dollars an acre, and maintenance costs about one dollar an acre per annum. Four small maintenance crews are employed on the salt-marsh maintenance. Fresh-water breeding is handled by the local communities, without state assistance. Funds for mosquito control in Connecticut have been inadequate for many years, but recently the annual appropriation has been somewhat increased.[2]

### State supervision

State supervision, and indeed a considerable measure of state control over local mosquito abatement work, is in our opinion highly desirable. In the first place, many local districts would be unable, on account of financial limitations, to employ highly skilled technical direction of their work, and the work must be performed by men who are less skilled but capable of doing satisfactory work under supervision. The state, on the other hand, can employ the few highly skilled supervisors necessary, and by using their services efficiently can obtain the maximum value from their specialized training and experience. In the second place, with state supervision, greater efficiency can be obtained from the local units through the introduction of improved methods, the analysis and comparison of unit costs, and the exchange of information between districts.

The logical department for such supervision by the state would appear to be the bureau or division of sanitary engineering in the state health department. There is so much engineering connected with mosquito abatement that this work would fit naturally and easily into such a bureau. Furthermore, the type of training (including biology and bacteriology) given to sanitary engineers in the more adequate universities is such that they can readily learn and apply the entomological principles involved. In many state divisions of sanitary engineering the addition of an entomologist to the staff is all that would be necessary; in others, especially if undermanned, one or more additional sanitary engineers may be required. It is also advisable and mutually beneficial to have a medical entomologist in the state university attached to the bureau staff as consulting entomologist.

However, a word of caution in regard to sanitary engineers (sometimes designated "public health" engineers) is in order. Many of them are products of colleges which give their engineering students little training in biological subjects. As a result, their viewpoint is much too mechanistic, and they require considerable additional training or re-training before they are of appreciable value in mosquito control work.

State supervision should include in its function the training of local mosquito abatement men in their duties. Such men could be brought to a central point at some time during the winter months for intensive courses designed to give them (through laboratory work, lectures, demonstrations, assigned reading, and examinations) a working knowledge of mosquito species, their life histories and habits, and control methods. The departments of entomology, hygiene, public health, and sanitary engineering in the state university could be brought into such a course of instruction with excellent results.

Financial supervision by the state, if free from purely political considerations, would also appear to be desirable. It would prevent to a considerable degree excessive or unwise local expenditures on the one hand, and local parsimony, which would result in ineffective work, on the other. It would also make possible long-time financial planning in districts having an extensive drainage problem.

In New Jersey, as previously stated, the county mosquito extermination commissions are under direct state supervision by the director of the state experiment station, who has the power to approve and modify the county budgets, and supervise and direct the work done. This type of supervision has worked well. It has one advantage, in that the supervision is technical rather than political. The New Jersey law also makes the state health officer, as well as the director of the state experiment station, a member ex-officio of all the county commissions, where his advice and influence can be of benefit, and the cooperation of the state health authorities assured.

### State university participation

In some states, the initiative in mosquito abatement work has been taken by some department of the state university, or by the college of agriculture. For example, the initial work demonstrating the practicability of mosquito abatement in California, both for salt-marsh mosquitoes and for anophelines, was done by members of the faculty of the College of Agriculture of the University of California; and education of the public as to the necessity and benefits of mosquito abatement was intensively carried on by the university with the cooperation of the state health department, until their efforts ultimately resulted in the passage of the mosquito abatement district act.

The University of California also sponsors the annual conference of mosquito abatement officials in the state (now the California Mosquito Control Association) which is of great educational value, and has helped to build an esprit de corps among these men. The proceedings of the annual conferences have been published in mimeographed form.

The New Jersey Mosquito Extermination Association, an unofficial organization of mosquito abatement personnel in New Jersey, holds annual meetings in March. The papers and discussions at these meetings are of great value, and are published annually in printed form.

The Eastern Association of Mosquito Control Workers, which meets annually or oftener, publishes *Mosquito News*, a quarterly which contains articles and news items of general interest to mosquito control workers.

## *FEDERAL AGENCIES*

Three federal agencies in the United States, exclusive of the military forces, concern themselves to some extent with mosquito abatement.

The Bureau of Entomology and Plant Quarantine in the Department of Agriculture has generally confined its activities in this field to research, and to extension work through the land-grant universities and agricultural colleges. An exception to this limitation of its activities occurred during the winter of 1933–34, when under the Civil Works Administration the bureau sponsored and directed mosquito abatement work[3] in many of the states. Principally work of permanent value, such as ditching, filling, and dyke construction, was undertaken. On February 15, 1934, this work was turned over to state sponsoring bodies, such as state health departments or state entomologists, until the conclusion of the emergency relief work in April. Though this program was intended primarily as an emergency measure for the relief of unemployed persons, and though the projects in many cases were hastily improvised, with inadequate engineering planning and entomological investigation, and suffered from governmental red tape, confusion of authority, and constantly changing rules and regulations, much good and useful work from a mosquito abatement viewpoint was accomplished. This work was continued under various relief agencies until about 1941, but while some work was well planned and directed, our impression of much of it was unfavorable.

The Bureau of Entomology and Plant Quarantine has done most commendable educational work through its bulletins dealing with mosquitoes. Its farmers' bulletins on the subject have been widely distributed and have contributed greatly to a public understanding of the mosquito problem. A former chief of the bureau, Dr. L. O.

Howard, was one of the pioneers in this field and did a great deal to popularize exact knowledge about mosquitoes and their habits.

The National Park Service carries on mosquito abatement work in the various national parks. Many of these parks are in high mountainous regions where the prevailing species of mosquitoes (*Aedes*) are especially difficult to combat successfully. In spite of the difficulties, the National Park Service with the cooperation of the United States Public Health Service has done a good job of mosquito abatement, and has greatly mitigated one of the worst drawbacks to serene enjoyment of these great vacation lands.

The Public Health Service on its own account has had a very distinguished experience in mosquito abatement work, both in practical measures and in research. It has been especially helpful in encouraging mosquito abatement work in the southern states where malaria is or has been endemic. Unfortunately, the service has not published a record of its accomplishments in mosquito control in cooperation with the various states.

During the first World War (1916–18) this service, under the designation of Extra-cantonment Sanitation, performed a large amount of mosquito control work in the vicinity of military establishments. In the present war, a division entitled Malaria Control in War Areas (MCWA) is operating in a similar manner, and is including *Aedes aegypti* control in addition to *Anopheles* control. Valuable new technical information and practical procedures are being developed by this division.

The Public Health Service maintains an office of malaria investigations, which is engaged in mosquito control studies incidental to investigations into the control of malaria. The Service has had among its personnel two men who have been outstanding in mosquito abatement work, the late Dr. H. R. Carter and Mr. J. A. LePrince; both have had a conspicuous part in the development of mosquito control methods.

### *NON-GOVERNMENTAL ORGANIZATIONS*

Several types of non-governmental organizations will upon occasion take active steps for the abatement of mosquitoes. In general, however, such organizations usually take the lead in initiating the work and in demonstrating its practicability and the value of its results, eventually turning the job over to some governmental agency to carry on. This has frequently occurred in regions where the local government was too "conservative" to take up a "newfangled notion" until public opinion was so strongly in favor of the work that the local government was forced to perform it.

In many communities a local organization such as the chamber of commerce, or a service club, or a women's club has taken the lead in initiating a mosquito abatement campaign. Such a club will endeavor to finance the work by means of public subscription or by various money-raising devices such as amateur theatrical performances, tag-days, and the like. This can be done for the first year with moderate success, but by the second year the financial returns from such methods become small and will almost entirely fail in the third year. Such community campaigns should be undertaken only for the purpose of demonstrating the practicability and desirability of mosquito abatement work, and with the intention of turning it over to the local government for continuance in subsequent years. The campaign should be not only a practical demonstration but an education of public opinion and a political drive upon the officials to compel them to take up the work. These three aspects should be kept in mind throughout, or the real objective, which is an effective official continuance of the campaign, will be missed.

Mosquito abatement has also been initiated and carried on occasionally by corporations with extensive land holdings, for their own direct benefit. In some cases, if the corporations did not do their own work, it would not be done at all; therefore they must do it as a matter of self-protection.

Frequently corporations will do certain types of drainage or oiling work on their properties as a measure of cooperation with various governmental agencies. Usually, the public service corporations, such as the railroads, electric light and power companies, and water companies, comply promptly and effectively with any reasonable request for abatement of mosquito breeding, either on their properties or caused by conditions existing on their properties. Occasionally this cooperation is refused, but as a rule it is given cheerfully and promptly, as a matter of good public policy and enlightened self-interest on the part of the utility. Our experience with these companies has been so uniformly satisfactory over a long period of years that we are inclined to think that where cooperation is refused there has been some defect in the manner of presenting the request. In other cases corporations have been able to abate mosquitoes with greater efficiency and at less cost with their own employees than if the work was performed by the local government. This is probably one of the reasons why the United Fruit Company carries on such extensive anti-mosquito work on its various tropical plantations.

Another type of non-governmental organization which engages in mosquito abatement work is the endowed philanthropic organization, of which the Rockefeller Foundation is a conspicuous example. The International Health Division of this foundation has carried on both practical mosquito abatement work and research in many malarial districts of the United States and other countries. In some cases it has performed the work directly with its own personnel and entirely at its own cost; usually it has furnished skilled planning and direction and shared the cost with the local government on a basis of gradually decreasing appropriations until the local community has absorbed the whole program. This form of promotion of mosquito abatement work has been on the whole very successful and beneficial, and though in some cases the community may fail to continue on an efficient basis after foundation support is withdrawn, nevertheless a community improvement well worth the expense and effort has usually resulted.

The brilliantly successful work performed by the Republic of Brazil in cooperation with the International Health Division in extirpating *Anopheles gambiae* from certain areas in Brazil[4] has been an outstanding achievement in methods as well as in results.

In addition, the work of several of the International Health Division's professional representatives in foreign (tropical) regions in past years has developed information which has been most valuable in the conduct of the present war.

Attention should also be called to the work of the Ross Institute of Tropical Hygiene (London) and its various branches in the British Empire. Much of the work of the Institute is supported by contributions from industries and individuals, particularly those having tropical properties and interests.

The Malaria Institute of India carries on research and demonstrations on malaria and mosquito control, and has contributed much to our knowledge of the subject. Its journal is an especially valuable publication.

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## IV

## PRELIMINARIES TO ABATEMENT PROCEDURES

Before any mosquito abatement is begun, it must be planned and organized, the proper personnel engaged, and adequate equipment and supplies provided. No matter how small the project, an adequate preliminary survey plus a well-conceived plan of operations is essential to success and economy. The larger the project, the more important it is that the preliminary work be well done.

Mosquito abatement projects are quite frequently promoted by laymen or by professional men such as engineers or physicians, who have only a very general idea of abatement procedures. They are concerned about the prevalence of mosquitoes, want to get rid of the pests, and have heard that spraying oil will eliminate them. So a committee is appointed to look into the matter; it finds out what laws, if any, are applicable; and from various sources, which seldom furnish information based on any extensive experience in mosquito abatement work, gets estimates of the approximate cost and perhaps a general plan of procedure.

Sometimes the state university or the state department of public health has a man on its staff who has had some experience in mosquito abatement work. But too often an entomologist or an engineer or a physician from such an agency is called in, whose knowledge of the work is more theoretical than practical. As his time is limited, usually only a day or so is spent in looking over the local conditions, and as a result the report rendered may be based on inadequate data. The advice may be free, which too frequently is worth just what is paid for it.

Under such conditions the results often are disappointing, or the cost exceeds the optimistic preliminary estimates. Even where abatement agencies have been organized as a result of a public agitation extending over a period of years, the tendency is to spend much effort on public agitation, and very little on obtaining sound technical advice and adequate plans and cost estimates.

### *PRELIMINARY SURVEY AND REPORT*

The services of an expert in mosquito abatement are most valuable in the preliminary stages for surveying the district and planning the organization. The best available man should be secured and his fee paid cheerfully. Usually a fund for organization expenses has to be raised by public subscription, from which the fee should be defrayed. Since much of the work can be done by subordinates, the total number of days of the expert's time is moderate.

The preliminary report should include data and recommendations on the following matters:

1. The boundaries of the region which should be included within the project
2. The population, area, and assessed valuation of the region
3. The species of mosquitoes involved, with a brief discussion of their breeding habits
4. The location and extent of the principal breeding areas
5. Tentative suggestions as to the best method of control for each principal breeding area
6. The amount and types of domestic mosquito breeding (such as *Culex pipiens*) within the region, and measures for its abatement
7. The probable organization that will be required, including personnel and equipment
8. Reasonably detailed preliminary estimates of cost, both for permanent work (including capital outlays) and for regular maintenance; and comparative costs for areas of similar size and conditions
9. The economic losses caused by mosquitoes in the area, and the economic savings which should result from adequate abatement measures

One of the purposes of this book is to supply information which, combined with the data obtained in the field, can be used in the preparation of the report. The detailed table of contents and index will be helpful in locating specific items.

## *STEPS TO BE TAKEN IN PRELIMINARY ORGANIZATION WORK*

### Selection of personnel

As soon as the project is organized, steps should be taken to obtain the proper personnel. The success of the work depends so greatly on the training and ability of the personnel that more care and thought should be given to this than to any other part of the problem.

### Board of trustees

If the work is to be supervised, especially as to policies and finances, by a board or commission, the proponents of the project should make the proper representations to the appointing power or powers so that only citizens who are outstanding for their character and ability will be appointed. The quality of the originally appointed board will set the example for future appointments.

It is advisable to have the members of the board or commission selected in advance and to suggest their appointment to the appointing authority. In making such a selection, it would be well to include an outstanding physician or two, an attorney (one who practices civil rather than criminal law), and the best civil engineer in the community. If there are in the locality university men trained in entomology or in sanitary engineering, one of each should also be included. The remainder of the board should be successful businessmen or farmers who have a deserved reputation for unselfish public service.

It is desirable that the board or commission should serve without compensation, except that any expenses incurred by them in the performance of their duties should be defrayed. In general, a non-pay appointment will be accepted by a much higher type of citizen than one to which a compensation is attached. In the latter case, there is too much temptation for mere political appointees.

### Executive officer

The most important duty of the board or commission is the selection of the executive officer. Upon his ability largely depends the success of the project. If possible, a man should be obtained who has at least the following qualifications: 1) successful experience in mosquito abatement work; 2) administrative ability; 3) university training in entomology and sanitary engineering; 4) good personality.

Agencies in large districts should be able to obtain such men, but in a small district they cannot as a rule afford to pay a sufficient salary to attract a highly experienced man and must then engage a different type—more a working foreman than an executive. As a rule, a recent university graduate in sanitary engineering, who has had some training in medical entomology, would appear to be the best type for the small project. Such men usually will remain for but one or a few years, to gain professional experience, but they can be replaced.

In recent years there has been a tendency to employ university-trained sanitary engineers on mosquito abatement work, for both civilian and military projects, regardless of whether or not they have had any training in medical entomology. Unfortunately, in many universities the training of sanitary engineers is deficient in the biological sciences, and such graduates are apt to have too mechanistic a viewpoint for the most successful mosquito control work.

The compensation for the executive officer will vary according to the size of the project, the complexity and difficulty of the abatement procedures, and the annual expenditures. It will vary also to a certain extent with the competence of the executive officer. In proportion to the annual expenditures for the work, the following range of annual salaries is suggested for the United States, based on the 1940 buying power of the United States dollar:

| | |
|---|---|
| Over $100,000 per annum | $6,000 to $10,000 |
| From $50,000 to $100,000 per annum | $5,000 to $8,000 |
| From $25,000 to $50,000 per annum | $4,000 to $7,000 |
| From $10,000 to $25,000 per annum | $3,000 to $5,000 |
| Less than $10,000 per annum | $2,000 to $3,000 |

Projects with large areas (over 200 square miles), large populations (over 250,000), or especially difficult problems of abatement should tend toward the higher salaries, and projects small in area, or with small populations, or simple problems should tend toward the smaller salaries. Pay for trained men assigned to foreign or tropical service should be materially higher than the salaries suggested for the United States.

In the first few years of work, the executive officer usually should be employed on a full-time basis. After the principal problems have been solved and a smooth-running organization obtained, his employment on a part-time basis may sometimes be sufficient.

In the large project, the executive officer is primarily an administrator, directing and coordinating the efforts of a staff of inspectors, foremen, and laborers, supervising the performance of various construction contracts, and handling the financial matters. He may have various technical assistants, such as entomologists and engineers, especially in the early stages of the work. He will need clerical assistance and should also have as an aid someone who can act as an educational publicist.

The direction of large-scale mosquito abatement requires marked ability as an executive as well as a unique combination of thorough knowledge of entomology, engineering, public health, and government. No one man can completely fill these specifications; therefore the executive officer will have to be supplemented by assistants who are specialists in particular subjects. For this reason the staff should not be appointed until after the election of the executive officer is decided and should then be picked with the idea of supplementing the executive officer.

It is interesting to observe that as far back as 1910 Ross[1] advised that the staff for malaria-mosquito control projects should consist of a malariologist (medical), an entomologist, a sanitary engineer, and a statistician.

### Division foremen

In large projects it is impossible for the executive officer to keep in immediate contact and direction with all the work. It is necessary to subdivide the area into sections or divisions which can be handled by one man and a crew of laborers. This man may be called a foreman or inspector, but regardless of title he must be directly responsible for all work in his division or section. He must be active, energetic, interested in his work, and able to handle a crew of laborers on ditching or oiling work. As he is in immediate contact with the public, he must have a pleasing personality and the ability to get along with people. He will require plenty of backbone plus self-restraint and much patience. He must be physically equal to sustained activity in the field, for the work is frequently arduous. It is important that these working foremen or inspectors be carefully selected, as they are the basis and foundation of successful work. Too much emphasis cannot be put on this point.

Salaries for the division inspector or foreman will vary with the size of the division, the importance and difficulty of the work, and to some extent also with the competence of the man. The range should run from not less than $2000 per annum minimum to about $4000 per annum maximum. Special cases may occur where salaries outside of this range would be paid.

These division inspectors or foremen should be retained on salary throughout the year, even though the mosquito breeding season is but seven or eight months long. Their intimate knowledge of every part of their territory is their greatest asset. Constantly changing these men will destroy the efficiency of mosquito abatement procedures. Good men seldom can be retained on a job where they are laid off for several months each year.

In order to keep experienced employees, it is advisable to allow reasonable vacation periods and sick leave, increasing with length of service. Also, where legally possible, there should be made available to the men some form of retirement allowance (pension), and probably group hospital and medical insurance.

### Laborers

Laborers must be physically equal to the heavy work of ditching and oiling, and in addition must have a good grade of intelligence. It will be found economical to pay a higher rate than the usual wage for laborers in order to obtain workmen who are better than average mentally as well as physically. A good labor gang is usually obtained only by weeding out the ones who prove unsuited to the work. Gradually a crew can be built up which is very satisfactory, but this takes time.

If foremen or straw-bosses are required, it is best to select them from the labor gang by promoting the most capable men. If they are needed only temporarily, they can be returned to the status of laborer when the need for them as foremen has ceased. Temporary promotions should, however, be definitely understood to be temporary, or morale will suffer.

### Clerical assistant

Large projects will require at least one full-time clerk-stenographer to take care of the office routine, the correspondence, and the clerical work of handling service requests or complaints. In small projects the executive officer will usually have to handle all office routine, possibly assisted by a part-time stenographer. Considerable care should be exercised in the selection and training of a clerk, as many complaints are received by telephone which must be handled courteously and in a manner to inspire public confidence.

In recent years, in the United States, the amount of clerical work required has greatly increased, due to the burden imposed by federal payroll taxes, rationing, priorities, questionnaires, and reports.

PROFESSIONAL ASSISTANTS

In large projects, also, especially if the area has a large urban population, it is necessary and desirable to employ, either on part time or full time, an educational and publicity assistant so as to relieve the executive of the detail work of newspaper publicity and perhaps also of some of the burden of speech-making.

Various technical assistants, such as entomologists, engineers, physicians, and attorneys, may also be required on large projects, either on whole time or part time. These specialists should be selected because of their special fitness for the work they are to perform. Their rates of pay will depend partly on the general scale of professional compensation in the region, and partly on the nature and extent of their services. In general, a professional man is employed on the basis of a retainer fee plus a fixed sum for each day actually spent on the work.

It is never possible to select and put into the field a staff that is thoroughly satisfactory from the start. Frequently the exact type of man required is not obtainable. There are also usually a number of errors in judgment in the selection of the initial personnel. Those first selected should be given careful training in their duties, and watched closely until it is certain that they can be depended upon. The unsuitable ones can be weeded out and replaced, until an organization that is reliable and efficient is built up. This is a most important duty of the executive officer.

## *PRACTICAL PREPARATIONS*

In mosquito abatement it is sensible to undertake a few preliminary procedures before beginning the actual attack on the mosquito breeding places. Maps of the area should be acquired and studied, a budget set up, funds obtained to defray the cost of the work, a system of accounts installed with a correlated purchasing scheme and a cost analysis method; an office should be provided and also a depot or warehouse to store and protect equipment and materials; and a system of recording the work and reporting on it should be devised. It is most advisable to give thought and careful attention to these necessary preliminaries, even in the face of pressure of public opinion to make a quick start on direct attacks on the mosquitoes.

## Maps

Thorough knowledge of the geography and topography of area is a very important item. As soon as the preliminary staff has been selected, it should begin to get acquainted with the territory. For this purpose adequate maps are essential and should be available at the earliest possible date.

The ordinary county or local maps are of little use in mosquito control work. Usually all they show are roads, principal towns, major streams, and property lines of the larger holdings. Frequently they are not up to date.

The best maps for mosquito abatement work are aerial photographic maps, made on a scale of about 500 feet to the inch. If such maps are not available, they should certainly be made at the start of the work. Properly prepared by a concern experienced in this work, and made with careful ground control for the exact location of important points, they are accurate and far more complete than any other type of map for this purpose. Two other advantages are the speed with which they can be obtained, and their low cost as compared with other methods of mapping. The cost will vary with the size of the project, the distance from centers where such work is done, and the extent of ground control work necessary.

Aerial photographic maps should be prepared to an exact standard scale, so that the distances can be correctly measured thereon. In general, a scale of 500 feet to the inch will prove satisfactory. A scale of 1000 feet to the inch is about the smallest limit which can be used. Larger scales than 500 feet to the inch are not required except possibly for limited areas of special importance. Aerial photographic contour maps are usually not needed and their cost is considerably greater.

If a salt-marsh area is involved, the map should preferably be made at the time of a low tide following a monthly high tide, as in this way the breeding areas left by the monthly high tides will be more clearly indicated.

Full-scale photographic reproductions of the original map on eight-by-ten-inch sheets may be put into ring binders and used conveniently in the field. Each sheet should be numbered and its location shown on an accompanying map which should be an eight-by-ten-inch reduced copy of the original map. Usually the maps will also be of great assistance to various officials, such as the county assessor and the county surveyor, who may be induced to help defray their cost.

Many areas of the United States had been mapped before the present war by various official agencies of government, and reproductions of these maps usually can be obtained at reasonable prices. In addition, a large amount of military mapping by aerial photography may be available after the war, in many parts of the world.

Maps are needed by several types of personnel for various purposes, among which are the following:

*Medical Officer*

1. Location of cases of mosquito-transmitted disease
2. Relative density of cases
3. Population density (human)
4. Vector densities
5. Location of breeding places of vectors
6. General supervision of control measures, including
   a. Locations of sub-stations
   b. Delimitation of sub-areas for control work
   c. Routing of inspection crews
   d. Routing of control crews
   e. Progress reports

*Entomologist*

1. Location, extent, and types of breeding places
2. Location of adult catching stations, light traps, etc.
3. Access routes to breeding places, stations, etc.
4. Flight studies
5. Studies of densities of adults, larval breeding, etc.

*Engineer*

1. Location of breeding places
2. Location of natural water courses
3. Planning of drainage, fills, etc.
4. Placement of flushing devices, etc.

Where adequate maps are not already available and aerial maps cannot be made, it will be necessary to prepare maps by means of ground surveys. Sometimes it will be possible to obtain an ordinary map of reasonably appropriate scale, or to photostat such a map to the required scale, and take it into the field, sketching thereon all details pertinent to mosquito control work.

Highly accurate surveying methods are seldom necessary for mosquito control purposes, though if very large areas are to be covered, one or more transit-and-tape traverse lines may be needed to tie the various map sections together properly.

The surveyor's plane table, with telescope alidade, making measurements (horizontal and vertical) by the stadia method, can be used to map large areas quickly and fairly accurately on reasonably open terrain. Less accurate surveys, though usually satisfactory, can be made with a simple sketching board mounted on a tripod, using a small compass; the telescope is replaced by a weighted triangular scale as an alidade or pointer; horizontal distances are measured by pacing, the number of paces being converted into lineal feet by means of a diagram. Special sketching boards (traverse sketching cases) of the type originally devised by Glenn S. Smith can also be used.

In the hands of a skilled topographer relatively simple mapping equipment can produce very useful maps rapidly, but the topographer must be taught what topographic and cultural features are significant for mosquito control purposes.

## Budgets

Mosquito abatement is usually performed by some governmental agency, either a department, bureau, or officer, or a district operating under a special legislative act. Irrespective of the particular type of governmental agency doing the work, it is as a rule necessary that the fiscal affairs of the department or district be conducted in accordance with a budget set up at the beginning of each fiscal year. Even if a formal budget is not required by law, both common sense and good business judgment require that some form of budget for all public expenditures be established. A budget is simply a financial plan for the conduct of work for one fiscal year.

At the inception of the work, the preparation of a budget is largely a matter of estimate which must be based principally on unit costs of approximately similar work. Such unit costs must be used with discretion and with intelligent adaptation to the particular case, as variation in the costs of mosquito abatement is great.

Rough average costs are of little value except to indicate a serious departure from a normal estimate. For example, in 1932 the averages for the New Jersey districts were 9.5 cents per capita, $101 per square mile, and 0.72 cents per $100 of assessed valuation. But the range for individual districts was very wide:

| | *Maximum* | *Minimum* |
|---|---|---|
| Cost per person | 22.6 cents | 2.0 cents |
| Cost per square mile | 2,120 dollars | 4 dollars |
| Cost per $100 of assessed valuation | 2.3 cents | 0.38 cents |

In California, in 1932, the averages were 19 cents per capita, $48 per square mile, and 2.5 cents per $100 of assessed valuation. The range was as follows:

| | *Maximum* | *Minimum* |
|---|---|---|
| Cost per person | 1.10 dollars | 6.8 cents |
| Cost per square mile | 566 dollars | 3 dollars |
| Cost per $100 of assessed valuation | 12 cents | 0.8 cents |

In general, it may be said that projects of large area and sparse population will show low costs per square mile and high costs per capita; compact projects with dense population will show low costs per capita and high costs per square mile. Primarily urban territory will show low costs per $100 of assessed valuation and rural territory will show high costs on the same base.

The best form in which to make up the first budget will be to estimate the items of expense, which may be conveniently grouped as follows:

*Salaries and Wages*

1. Director or superintendent
2. Clerk-stenographer
3. Inspectors or foremen
4. Laborers
5. Special services
   a. Entomologists
   b. Engineers, surveyors, draftsmen
   c. Educational and publicity experts
   d. Physicians
   e. Attorneys
   f. Auditors

*Maintenance and Operation*

1. Motor vehicle supplies
   a. Gasoline and oil
   b. Greasing, cleaning, etc.
   c. Tires and tubes
   d. Miscellaneous
2. Office supplies
   a. Printing and stationery
   b. Maps
   c. Miscellaneous
3. Miscellaneous supplies
   a. Oil
   b. Larvicides
   c. Tools

*Maintenance and Operation (cont.)*

Miscellaneous supplies (*cont.*)

- d. Rubber boots
- e. Lumber
- f. Miscellaneous

4. Communication
   - a. Telephone and telegraph
   - b. Postage
5. Travel expense
6. Water, light, heat, and power
7. Rents
   - a. Garage
   - b. Other
8. Repairs and replacements
   - a. Automobiles and trucks
   - b. Fixed equipment (tide gates, etc.)
   - c. Office furniture and fixtures
   - d. Miscellaneous
9. Special services and contracts
   - a. Contracts on drainage and fills
   - b. Contracts on ploughing

*Maintenance and Operation (cont.)*

   - c. Miscellaneous special services

10. Insurance
    - a. Workmen's compensation insurance
    - b. Automobile insurance
    - c. Other insurance
11. Interest on borrowed money
12. Retirement allowance fund

*Capital Outlay*

1. Passenger cars, motorcycles, and trucks
2. Launches and boats
3. Power spraying equipment
4. Power excavating equipment
5. Office furniture and equipment
6. Culverts and tide gates
7. Pumping equipment
8. Miscellaneous capital outlay

*Cash Basis Fund*

*Contingencies*

It is desirable that a reasonable allowance be made for unforeseen contingencies. Also, if there is a poor correlation between the beginning date of the fiscal year and the time when taxes are paid, it will be necessary to include in the budget a cash basis fund. In some states the fiscal year begins on July first, but the first installment of taxes is not delinquent until December. As a result, there is a space of five months during which the tax revenue is negligible. To take care of this situation, it is necessary to secure cash with which to carry on operations between the beginning of the fiscal year and the time that the first installment of taxes is paid. This amount must be estimated and added to the initial budget and then carried over as an available balance into the fund for the succeeding fiscal year. For this period in the first year of operations, it may be necessary to borrow money in some manner and in that case an allowance for interest on borrowed money should be included in the first budget. The laws governing this matter should be carefully ascertained and a thoroughly legal procedure followed.

It is very desirable that the original budget, at least, be prepared under the supervision of someone who is experienced in this work, and that a definite budget form be adopted and adhered to. Many jurisdictions have laws or regulations covering the budgeting of expenditures of local governments and these should be ascertained and conformed to. It may take a little ingenuity to adapt an adequate mosquito abatement classification of expenditures to the required budget form.

After the first year of operations budgets can be more intelligently and accurately prepared from the accounts of expenditures in previous years, especially if the accounts have been properly classified and properly kept.

### Finances and accounting

A definite financial and accounting procedure should be adopted at the commencement of the work and scrupulously adhered to. It is desirable that a certified public accountant be employed to plan the accounting system and to check the accounts periodically. Semi-annual audits are usually satisfactory. All agencies handling public funds should require at least an annual audit of their accounts.

The accounting system should be as simple as possible, so that it can be handled with a minimum of time and effort by the clerk under the supervision of the executive officer, or by the executive officer himself. The system should show the executive officer the exact status of all revenues and expenditures and the exact amount of the available cash balance at any time. The accounts must also, in many cases, be reconciled with those of some public officer, such as the county auditor or the county treasurer, and in some states are subject to review or control by a central state agency. If the funds of the project are in the custody of the county treasurer or of some state department or official, frequent check of receipts and disbursements should be made. This should be done at least monthly, and in large projects preferably oftener.

While the accounts must be organized so as to comply with any state or local regulations, their primary purpose, of furnishing a record of the cost of abatement work and a means of control for keeping within the limitations of the annual budget and current cash, should be kept constantly in mind. Successful abatement work depends not only on adequate measures taken in the field, but also on careful financial management which ensures that funds for such work will always be available when needed.

Although it is easy to say that expenditures should be kept within the budget allowances, it is not easily carried out unless there is a definite plan of expenditure and unless the accounts will enable the executive officer to know at all times where he is with reference to such a plan. For this reason rates of expenditure should be set up for the various items. Some items, such as insurance, are usually paid in a lump sum for an entire year (fire insurance ordinarily for three years). These amounts are paid usually in the first month of the fiscal year. Other items, especially of capital outlay, will also occur in lump sums but not necessarily at definite or regular times. Many of the remaining items of expense, however, are fairly constant from month to month or vary with some degree of regularity according to seasonal conditions. Requirements for oil and larvicide are of the latter type. These expenditures can all be accounted for monthly on a "rate of expenditure" sheet attached to the budget. If an estimate of receipts from anticipated taxes and other sources is set forth monthly, the proper rate of expenditure can be calculated to keep within the budget and to maintain adequate operations. Also the total amount required for the cash basis fund can be calculated. This "rate of expenditure" sheet, with the budget, will form a satisfactory financial plan of the work. It should not be departed from except for compelling reasons.

Special districts may require special drafts or warrants for any payment out of the funds of the district. The state or local laws pertaining to these should be determined and carefully conformed to.

### Purchasing

Before any work is begun, a routine procedure for handling all purchases should be established, and printed order forms prepared. In some municipalities and counties all purchasing is done by the city or county purchasing agent, in which case the forms and procedure required by municipal or county law or regulations must be conformed to. In special districts which do their own purchasing direct, it is advisable to conform as closely as possible to the forms and procedure in use by the purchasing agency of the county. It is also desirable to keep in touch with the county purchasing agent as he can be of considerable assistance in obtaining lower prices or better quality of materials.

A central purchasing agency usually issues purchase orders direct to vendors upon requisitions prepared by a department head. A mosquito abatement district doing its own purchasing will usually not require a requisition form.

If the project does its own purchasing, the executive officer will usually have to be the purchasing agent. The routine clerical work can be handled by the clerk in the larger projects, but the executive officer should maintain a close supervision over all purchases.

A purchase order form should be made in triplicate, the original going to the vendor, a duplicate going to a numerical file, and the triplicate being attached with invoices to the copy of the draft or warrant paying for the purchase. Where there is a central purchasing department, the purchase order is made in quadruplicate, the fourth copy going to the department making the requisition.

All orders should be carefully worded and the information should be complete and precise so that there can be no question as to exactly what is being ordered. If the material is ordered from a catalogue, the page and item number should be given. If material of a special composition is ordered, such as larvicide, precise specifications as to its characteristics should be attached to the order.

Local laws or regulations should be consulted and followed as to requirements in the matter of obtaining bids. Usually on purchases exceeding a certain maximum amount (often $500) it is necessary to advertise for bids. But even when bids are not required, prices should be obtained, wherever possible, from several different vendors on all items except minor purchases.

In projects including several communities, it is not desirable to confine all purchases to the principal commercial center, even if lower prices are obtainable there. It is a good policy to spread at least minor purchases over all parts of the area—it helps to make friends of the merchants. Records should be kept of vendors and their prices, at least on all articles likely to be purchased frequently. Card records may be used for this purpose.

Some materials, such as gasoline, lubricating oils, and spray oil, may be most satisfactorily purchased on an annual contract for the estimated requirements of the project. Materials such as shovels and other minor items may be purchased in quantity equal to requirements for six months or a year, and issued to the field forces as needed. Quantity purchases, however, should be made only of materials or supplies which do not deteriorate and only in case they can be safely and economically stored. Discounts on quantity orders may often be obtained and also discounts for prompt payment of bills. Every effort should be made to take advantage of such discounts. In a large district they may amount to an appreciable saving each year.

## Reports

Before any work is begun, a form of daily report on all work should be devised. The function of a daily report is to give succinct information as to what was done, what quantities of labor and materials were used, and what collateral expenses, such as transportation, were chargeable to the work. The report form must not be so complex that its making is a burden. It should be adapted to the various classes of work and should show precisely the quantity of each type of work and its direct cost in labor and materials. However, it must be sufficiently simple so that the inspectors or foremen can make it up daily without excessive clerical work. Unless the normal tendencies of bureaucrats and efficiency experts in this last respect are curbed, the field men will degenerate into mere report makers and abatement work will suffer.

Pages 70 and 71 (Figure 2) show the face and back of a form of daily report which has been in use for several years and has been quite satisfactory. The white original goes to the central office and a yellow copy is retained by the foreman.

Figures 3, 4, and 5, with the accompanying instructions on the reverse of Figure 3, are report forms developed by the United States Public Health Service for the use of inspectors working on *Aedes aegypti* control projects, and are presented as examples of the type of reports useful in recording detailed information procured on systematic inspection work. Somewhat similar reports can be prepared for recording corrections of mosquito breeding on this type of project.

From the daily reports a compilation should be made for each month and should be incorporated into a monthly report. The com-

**ALAMEDA COUNTY**
**MOSQUITO ABATEMENT DISTRICT**
New Court House, Oakland

Date ______________________

Division ______________________

## DAILY REPORT OF DIVISION FOREMAN

Man-Hours Labor: | F | S | L |

CONSTRUCTION — Location

Size — Length — Cubic Yards

DITCH & SLOUGH MAINTENANCE

Size — Length

BURNING

Acres — Gals. Oil

OILING

Location — Length — Acres — Gals. Oil — Gals. Kero. — Qts. Larv.

MISCELLANEOUS OILING

No. Places — Gals. Oil — Gals. Kero. — Qts. Larv.

GAMBUSIA DISTRIBUTION — No. Places

NO. COMPLAINTS HANDLED

INSPECTIONS

MISCELLANEOUS

(OVER)

Figure 2. Form of daily report (face)

## TIME DISTRIBUTION

Date ____________

| NAME | TOTAL HOURS | ENGR | INSP | CONST | OILING | MAINT | COMPL | FISH | OVER-HEAD |
|---|---|---|---|---|---|---|---|---|---|
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## EXPENSE

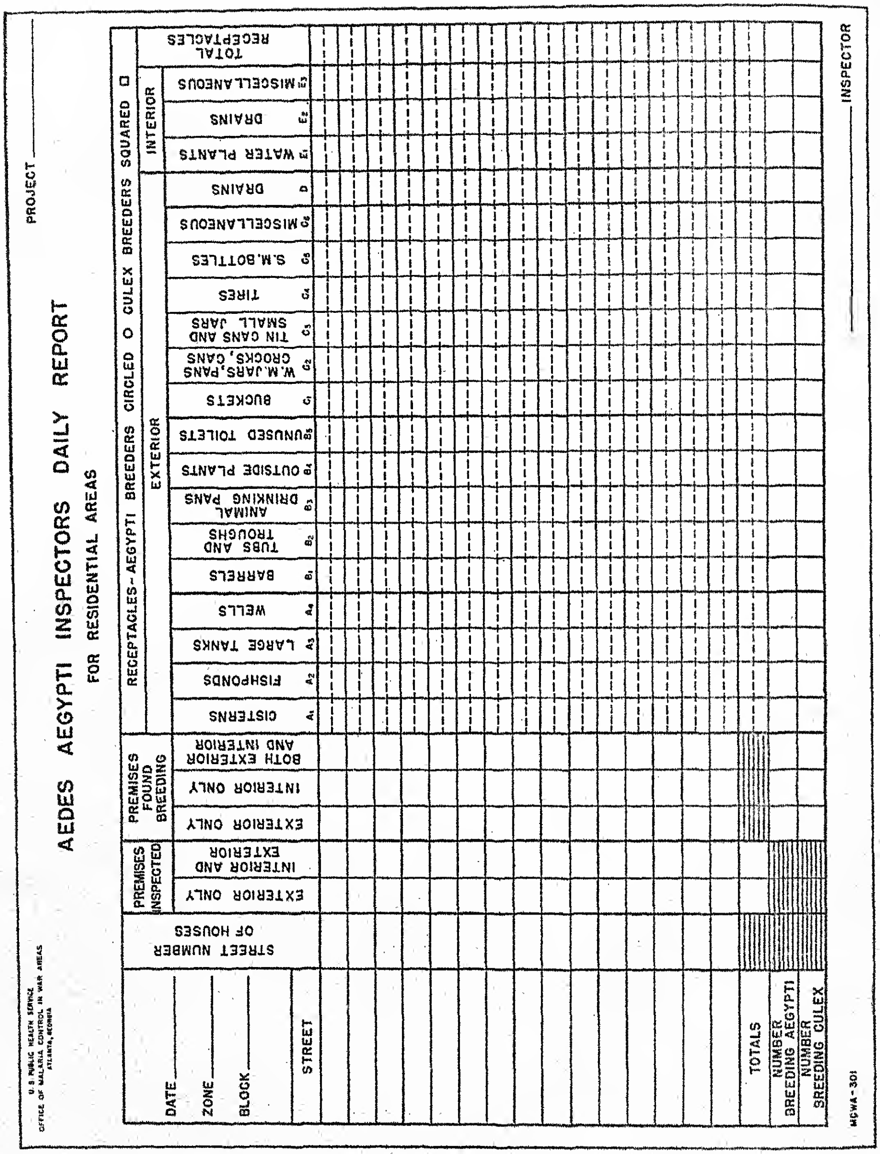
**Truck No.** ____________ **Speed. Read.** ____________ **Mileage Today** ____________

## REMARKS

____________________

DIVISION FOREMAN

Figure 2. Form of daily report (back)


U.S. PUBLIC HEALTH SERVICE
OFFICE OF MALARIA CONTROL IN WAR AREAS
ATLANTA, GEORGIA

PROJECT ________

AEDES AEGYPTI INSPECTORS DAILY REPORT

FOR RESIDENTIAL AREAS

| DATE ____ ZONE ____ BLOCK ____ STREET | STREET NUMBER OF HOUSES | PREMISES INSPECTED: EXTERIOR ONLY | PREMISES INSPECTED: INTERIOR AND EXTERIOR | PREMISES FOUND BREEDING: EXTERIOR ONLY | PREMISES FOUND BREEDING: INTERIOR ONLY | PREMISES FOUND BREEDING: BOTH EXTERIOR AND INTERIOR | RECEPTACLES – AEGYPTI BREEDERS CIRCLED O CULEX BREEDERS SQUARED □ — EXTERIOR: $A_1$ CISTERNS | $A_2$ FISHPONDS | $A_3$ LARGE TANKS | $A_4$ WELLS | $B_1$ BARRELS | $B_2$ TUBS AND TROUGHS | $B_3$ ANIMAL DRINKING PANS | $B_4$ OUTSIDE PLANTS | $B_5$ UNUSED TOILETS | $C_1$ BUCKETS | $C_2$ W.M. JARS, PANS CROCKS, CANS | $C_3$ TIN CANS AND SMALL JARS | $C_4$ TIRES | $C_5$ S.M. BOTTLES | $C_6$ MISCELLANEOUS | D DRAINS | INTERIOR: $E_1$ WATER PLANTS | $E_2$ DRAINS | $E_3$ MISCELLANEOUS | TOTAL RECEPTACLES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NUMBER BREEDING AEGYPTI | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NUMBER BREEDING CULEX | | | | | | | | | | | | | | | | | | | | | | | | | | |

MCWA-301

________ INSPECTOR

Figure 3. Report form for residential area inspections (front)

The "Inspector's Daily Report for Residential Areas" shall be used by inspectors making routine house to house inspections. For purposes of this report a residential area is defined as a section devoted primarily to individual housing units.

The term premise shall be defined, for purposes of this report, as any housing unit plus its surrounding ground. Occasional stores, churches, filling stations, etc., occurring within a predominantly residential area shall be included on this form. Small apartment houses in residential areas shall thus be listed as one premise. A vacant lot, regardless of size, shall be recorded as one premise if actually searched for containers by the inspector. A tourist court or trailer camp shall be listed as one premise.

Receptacles shall be classified into two categories: (1) Those containing water, called "possibles," and (2) those which are dry but which are "potential possibles" because they will catch water in the event of rain. Containers with water shall be listed above the dashed line while potential possibles shall be listed below the dashed line.

The inspector should list only actual possible breeding containers or potential possible breeding containers. Containers with water which obviously will soon be eliminated or emptied by the housewife should not be included. The following are examples of containers with water which in general do not constitute a breeding hazard and therefore should not be included as possibles:

1. Regularly changed animal drinking pans
2. Regularly changed flower vases
3. Buckets, tubs, etc., with wash-water which will be emptied as soon as the washing has been completed
4. Pots, pans, etc., on stoves holding water to be used in cooking the day's meals
5. Regularly used toilets

Dry containers should not be included unless they are exposed so that they can reasonably be expected to hold water after a rain.

When more than ten containers in one classification are found they should be recorded as 10+. Thus a pile containing fifty cans of which twenty contained water would be listed as 10+ wet and 10+ dry.

The number of containers breeding *aegypti* should be circled while the number breeding *culex* should be squared. Those breeding both should be enclosed by a circle within a square. Thus in the above example, if three containers were breeding *aegypti* only, and two breeding *culex* only, the figures recorded would be: $10 + \frac{\textcircled{3}}{\boxed{2}}$. Again, if three cans were breeding *aegypti* only, one breeding *aegypti* and *culex*, and two breeding *culex* only, the figures recorded would be $10 + \frac{\textcircled{3}}{\boxed{\textcircled{1}}}\boxed{2}$. The major figure shown will always include the secondary figures. Thus if there were nine tires all with water of which six were breeding *aegypti* the figures would be recorded thus, $9\ \textcircled{6}$, the major figure (9) including the secondary figure ($\textcircled{6}$).

Under the columns titled "Premises Found Breeding" place a circle for an *aegypti* breeder found and a square for a *culex* breeder found.

Figure 3. Report form for residential areas (back)
Instructions for use

U. S. PUBLIC HEALTH SERVICE
OFFICE OF MALARIA CONTROL IN WAR AREAS
ATLANTA, GEORGIA

PROJECT ____________

# AEDES AEGYPTI INSPECTORS DAILY REPORT

## FOR BUSINESS DISTRICTS

DATE ____________

ZONE ____________

BLOCK ____________

| STREET | STREET NUMBER | NAME OF BUSINESS | ESTABLISHMENTS — INSPECTED: EXTERIOR ONLY | ESTABLISHMENTS — INSPECTED: INTERIOR AND EXTERIOR | ESTABLISHMENTS — FOUND BREEDING: EXTERIOR ONLY | ESTABLISHMENTS — FOUND BREEDING: INTERIOR ONLY | ESTABLISHMENTS — FOUND BREEDING: BOTH EXTERIOR AND INTERIOR | RECEPTACLES — AEGYPTI BREEDERS CIRCLED ○ CULEX BREEDERS SQUARED □: CISTERNS AND WELLS A1 | LARGE TANKS A2 | ELEVATOR PITS A3 | OTHER PERMANENT A4 | BARRELS B1 | TUBS AND TROUGHS B2 | OTHER SEMI-PERMANENT B3 | SPITTOONS C1 | TIRES C2 | CANS AND BOTTLES C3 | BUCKETS AND PANS C4 | WATER PLANTS C5 | OTHER TEMPORARY C6 | DRAINS D | TOTAL RECEPTACLES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | |
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| TOTALS | | | | | | | | | | | | | | | | | | | | | | |
| NUMBER BREEDING AEGYPTI | | | | | | | | | | | | | | | | | | | | | | |
| NUMBER BREEDING CULEX | | | | | | | | | | | | | | | | | | | | | | |

MCWA-303

____________ INSPECTOR

Figure 4. Report form for commercial area inspections

U. S. PUBLIC HEALTH SERVICE
OFFICE OF MALARIA CONTROL IN WAR AREAS
ATLANTA, GEORGIA

PROJECT ____________
STATE ____________
FROM ________ TO ________

## PROGRESS REPORT — AEDES AEGYPTI CONTROL

| I. RESIDENTIAL AREAS | EXTERIOR ONLY | INTERIOR ONLY | EXTERIOR AND INTERIOR | TOTAL INSPECTION | TOTAL INTERIOR | TOTAL EXTERIOR | EXTERIOR: CISTERNS $A_1$ | FISHPONDS $A_2$ | LARGE TANKS $A_3$ | WELLS $A_4$ | BARRELS $B_1$ | TUBS AND TROUGHS $B_2$ | ANIMAL DRINKING PANS $B_3$ | OUTSIDE PLANTS $B_4$ | UNUSED TOILETS $B_5$ | BUCKETS $C_1$ | W.M. JARS, PANS, CROCKS, CANS $C_2$ | TIN CANS AND SMALL JARS $C_3$ | TIRES $C_4$ | S.M. BOTTLES $C_5$ | MISCELLANEOUS $C_6$ | DRAINS D | INTERIOR: WATER PLANTS $E_1$ | DRAINS $E_2$ | MISCELLANEOUS $E_3$ | TOTAL RECEPTACLES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PREMISES INSPECTED | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PREMISES BREEDING AEGYPTI | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PREMISES BREEDING CULEX | | | | | | | | | | | | | | | | | | | | | | | | | | |
| AEGYPTI INDEX | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONTAINERS FOUND - WITH WATER | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONTAINERS FOUND - DRY | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONTAINERS BREEDING AEGYPTI | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONTAINERS BREEDING CULEX | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONTAINER INDEX - AEGYPTI | | | | | | | | | | | | | | | | | | | | | | | | | | |

| II. NON-RESIDENTIAL AREAS | NUMBER INSPECTED | NO. UNITS (BLDGS., WHARVES, ETC.) | NUMBER UNITS FOUND BREEDING | FIRE-BARRELS CORRECTED |
|---|---|---|---|---|
| WAREHOUSES AND WHARVES | | | | |
| INDUSTRIAL PLANTS | | | | |
| MILITARY BASES | | | | |
| BUSINESS ESTABLISHMENTS | | | | |
| OTHERS (SPECIFY) | | | | |

| III. EDUCATIONAL ACTIVITIES | |
|---|---|
| 1.- NEWSPAPER ARTICLES PUBLISHED (SUBMIT COPIES) | |
| 2.- TALKS - PUBLIC | |
| 3.- PAMPHLETS DISTRIBUTED | |
| 4.- TALKS - RADIO | |
| 5.- MOVIE TRAILER SHOWINGS | |
| 6.- OTHER (SPECIFY) | |

| IV. LABOR SUMMARY | | | |
|---|---|---|---|
| MAN HOURS | USPHS | OTHER | TOTAL |
| RESIDENTIAL PREMISE INSPECTIONS | | | |
| EDUCATIONAL ACTIVITIES | | | |
| OTHER | | | |
| TOTAL | | | |

MCWA-304

NOTE: PLACE NARRATIVE REPORT ON BACK OF THIS SHEET

____________ AREA SUPERVISOR

Figure 5. Report form for periodical inspections

pilation, to be systematic and uniform, should be made on a special form.

The monthly report should contain a narrative of important or interesting matters of mosquito abatement during the month, tabulations of the quantities of the various kinds of work performed, their individual gross and unit costs, and a statement of expenditures for the month classified according to the budget segregations. In some cases it may also be desirable to include the receipts from taxes and other sources and the available cash balance at the end of this month.

While a copy of the monthly report should be sent to the newspapers, the editors will seldom take the trouble to read it carefully and prepare an adequate newspaper story on it. Occasionally the papers will draw unwarranted conclusions from a technical statement of fact or, lacking interpretations, may distort the real meaning of various items. Therefore it is desirable that the executive officer or someone familiar with publicity methods prepare newspaper stories outlining the salient features of the report. If there are several newspapers it is desirable to vary the write-up for each paper.

From the monthly reports should be compiled an annual report. Regardless of how the fiscal year is timed, the annual report should be made for the calendar year for countries in the north temperate zone. In the south temperate zone a report year ending June 30 may prove more suitable, that date corresponding climatically to December 31 in the north temperate zone. The report year should correspond at least approximately with the mosquito breeding year so as to include each annual season as a unit for report purposes.

Statistical material in the annual report, while it should be complete, should be placed at the end of the report. The body of the report should be a narrative of the more important events and accomplishments during the year, introduced by a few pithy paragraphs in which the meat of the report is condensed in an interesting and striking manner. It must be remembered that few people, except those technically interested, will study an annual report. Most persons will read the first page or two if it is interestingly written, merely glance at the remaining pages, and balk entirely at tables of quantities and costs.

From time to time special reports should be made on distinct phases of the work, on each contract job, and on unusual outbreaks or flights of mosquitoes.

### The project office

All except the very smallest projects will require a central office for the conduct of business. Very large projects may require branch offices as well.

It is essential that the office be properly equipped and organized for the efficient conduct of business. It should be plain and without frills, but adequate. One or more desks as needed, a table, a drafting board, chairs, filing cabinets for records, and a storage cabinet for office supplies are usual equipment and may frequently be purchased secondhand. A typewriter and adding machine are also necessary but should usually be purchased new, though rebuilt machines may be satisfactory.

A small duplicating machine, such as a "Ditto," is very desirable for getting out copies of reports, notices, and circular letters. If very much work of this kind is done, a mimeograph may be desirable, though as a rule if mimeographing is required it will be better to cut the stencils in the office and have the printing done by a local mimeographing firm.

Maps of the project should be mounted on boards, for which plywood is very satisfactory though cheaper boards will do.

### Depots or warehouses

Mosquito abatement agencies will almost always require some kind of depot or place for keeping equipment and materials used in the work. In some cases space can be obtained in existing facilities operated by the county or city, but in most cases it will be necessary to rent or acquire some form of depot.

At the beginning of work it will probably be advisable to rent space at some convenient and reasonably central point, but if the project is of any size and permanence, land should be purchased within a few years and the necessary facilities constructed or installed. In the larger projects, especially if the work is divisionalized, several depots may be advisable.

A lot fifty by one hundred feet is usually ample. On it should be constructed a combined garage, warehouse, small shop, and office. If one truck only is to be garaged, a floor space of eighteen by twenty-four feet net inside dimensions will be found sufficient. If additional automotive equipment is to be housed, the dimensions should be increased accordingly.

It is desirable to provide in this building a shower bath with water heater, a toilet, wash basin, and lockers for the comfort of the men.

An underground steel tank for oil storage at each depot is advisable, as the savings on quantity purchases of oil will usually defray the cost of the tank and pump in a few years. For a similar reason a steel underground storage tank and pump for gasoline is also advisable. To ensure reasonable service life, underground steel tanks should be given an outside prime coat of pure red lead in oil plus two heavy coats of a good coal-tar protective paint.

Capacities of the oil tank should range from about 3000 to 6000 gallons, according to oil marketing practices in the particular area. The oil companies should first be consulted as to the unit delivery quantities at which price discounts are available. In some cases depots should be located on railroad sidings to take advantage of tank car delivery prices.

If heavy equipment, such as power cranes, caterpillars, power sprayers, and the like, are owned, protective sheds should be constructed for such equipment.

The depot grounds should be fenced, preferably with an industrial type wire mesh fence, if sufficient money is available. The grounds and structures should be kept clean and in order, the building well painted, and a reasonable effort made to have the depot look shipshape at all times.

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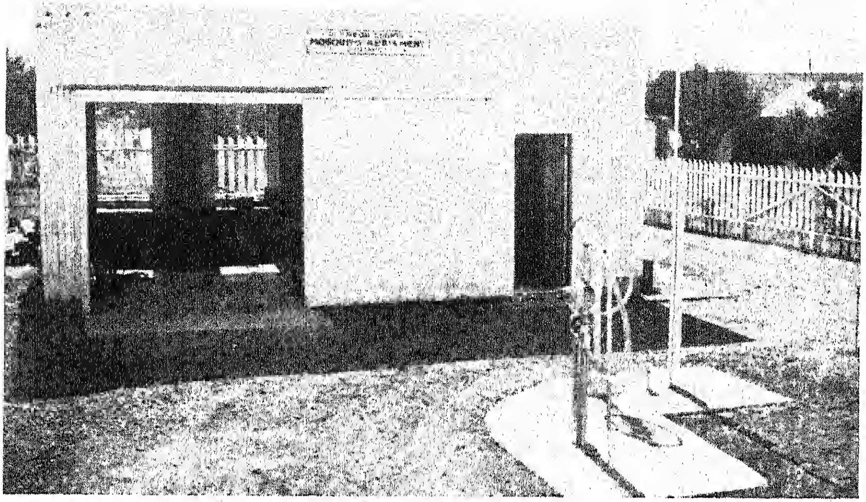

Figure 6. Divisional depot of a mosquito abatement district. Pumps for spray oil, from underground storage tanks, in right foreground; warehouse in rear

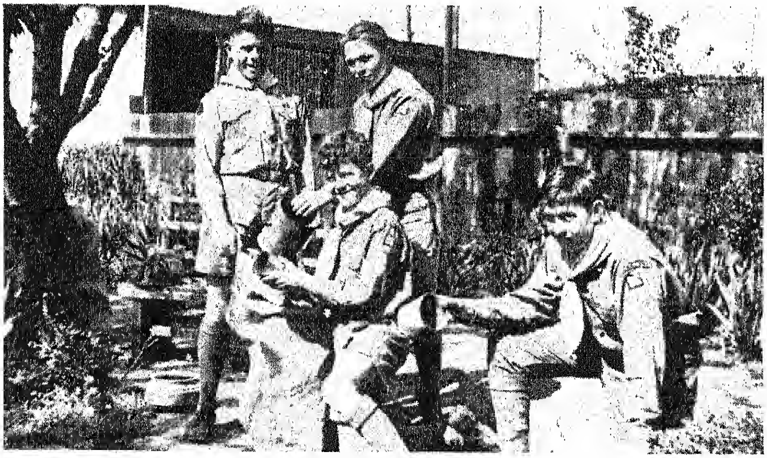

Figure 7. Boy Scouts at work on neighborhood spring clean-up of mosquito breeding containers

# V

# EDUCATION OF THE PUBLIC

It might be expected that a community suffering from mosquitoes would rush to take advantage of any workable proposal that would abate the nuisance. Yet experience has shown that even in communities where malaria is rampant a great deal of promotion is required to get the residents to back a mosquito abatement program.

In order to organize mosquito abatement work you must convince the people of a community: 1) that the mosquitoes constitute a health menace or a considerable handicap to the comfort and development of the community; 2) that it is worth while to spend money to remove this menace or handicap; 3) that the mosquito nuisance can be satisfactorily controlled; and 4) that the cost of abolishing the mosquito will be reasonable. It takes a great deal of publicity, in one form or another, first to convince the people on these four points, and then to get them to act on their convictions. Even after a mosquito abatement project has been established and is in operation, it is still very important to continue to inform and educate the public.

In the first place, a mosquito is just a mosquito so far as the average resident is concerned. He is not able to distinguish between mosquitoes that come from a distant marsh and those that are breeding in his neighbor's garden pond or in his own rain barrel, nor does he care to. In this attitude the average resident is right. If the taxpayers furnish money for the control of mosquitoes, all mosquitoes, as far as possible, should be effectively controlled, both the migratory *Aedes* species and the local or domestic species, under normal urban or rural conditions.

There may be an occasional abatement project so small that workers are able to inspect every resident's yard every week during the mosquito season. However, in the case of most mosquito abatement projects there is a large area to be controlled and only a small force to do the work. Under these circumstances it is essential to teach the public how to avoid raising mosquitoes, in order to prevent the breeding of a great many in collections of water on residential and business premises.

A second point is this: the bulk of mosquito abatement work is done by governmental agencies which are supported by taxation. As taxpayers who foot the bill, the residents of a district are entitled to know why and how their money is being spent.

Let the residents of your district know about the work you are constantly doing—the regular oiling of creek beds, dairy drains, sewer catch basins, and other mosquito breeding places, the clearing of ditches in drained swamps and marshes, and all the rest of the many phases of mosquito control. Keeping the public informed as to what is actually being done will avert a great deal of uninformed criticism.

Any governmental agency, even one engaged in such a technical field as mosquito abatement, is to a greater or less degree subject to political pressure and influence. You will be in a better position to do an efficient job if you have the support of the general public. To gain and hold that support calls for a definite program of education and publicity.

A business man desiring to sell a product or a service relies heavily on paid advertising, in magazines and newspapers, on billboards, and over the radio. Governmental agencies ordinarily do not employ paid advertising as a means of publicity, though there is no logical reason why they should not do so. Possibly they feel that they would be criticized for spending public funds on advertising designed to keep them in their jobs. In some cases there are legal prohibitions against advertising.

The principal means of public education open to mosquito abatement agencies are: 1) newspaper publicity; 2) speeches, including radio talks and the use of motion pictures or slides; 3) exhibits; 4) informative pamphlets; 5) house-to-house inspections; and 6) tours of inspection. Many of these forms of public education are tied in together. A speech will probably accompany the showing of a motion picture or lantern slides. Explanatory pamphlets will be distributed at an exhibit and during a house-to-house inspection. The report of a speech, of an exhibit, or of a tour of inspection should be given to the local newspapers.

All these means of publicity may be employed both while endeavoring to organize a mosquito abatement project and after the project is in operation. Naturally, the objectives are different. In the first case you will be arousing the public to take direct action—to organize an abatement project—while in the latter case you wish primarily to report progress and to maintain public interest.

The mosquito abatement superintendent ordinarily must be a combination of engineer, entomologist, public health authority, and executive. It is perhaps piling things on too much to expect him to be a newspaper man, public speaker, and advertising expert as well. Consequently an abatement project able to stand the expense can employ a publicity director to advantage, at least for part-time work. Such a man should be able to deal with the public more easily and effectively than can the superintendent. His employment also will enable the superintendent to concentrate on the task at hand—controlling mosquitoes—without being diverted by the need for publicity writing and speech-making.

This discussion must be considered only as a suggestive outline of methods of educating the public as to the need for mosquito abatement and for its continuance on an effective basis. If the project is small and located in a rural area most of the residents of the district will know of the work from personal contact with the workmen. This does not mean that there is no use for news stories, speeches to organizations, and other means of publicity. That is always necessary. However, each project will have its own peculiar setup and its own problems and must work out its own variations of the methods suggested.

### Newspaper publicity

Everything done by the abatement project and its employees that affects and will interest a considerable number of residents of the district is legitimate news and should be written and given to the newspapers for publication as a news item.

When endeavoring to establish a mosquito abatement project, local editors should be advised of each step in the progress of the campaign. A story about the selection of a committee to promote the project, the raising of funds, the announcement of a speech to be made at a service club or at an open meeting, and the report of such a speech, will ordinarily be printed—unless, of course, the newspaper publisher is definitely opposed to the work or mistakenly believes that any suggestion of the necessity of mosquito abatement is bad publicity for the community. Such editors may be encountered, though they are very few compared with the number thirty years ago.

When an expert is employed to make an estimate of the work necessary in the proposed abatement project, his report should be given to the local papers. Prominent citizens favorable to the plan should be asked to make statements to the papers. When some civic or social organization endorses the campaign, see that notice of the endorsement is given to the paper. If a newspaper can be persuaded to campaign actively for mosquito abatement, give the editor the story of how mosquitoes have been eliminated in other parts of the country, and provide him with information to be used in articles or editorials explaining the advantages to be gained by ridding the community of these pests.

Continue to maintain cordial relations with the press after the project has been established. Initially the papers may come to the superintendent for news. Later the superintendent (or his publicity man) will have to go to them.

The following things are obviously news: employment of a superintendent; setting of the budget or appropriations for abatement work; hiring of laborers; letting of contracts; purchase of equipment; initiation and completion of a drainage project. These things are also news: speeches about mosquito abatement; a tour of inspection of work in progress or completed; an exhibit of abatement work; parts of the superintendent's monthly report.

Beyond the items mentioned above is a wide field of feature articles and human interest material. Included in the human interest group are such items as: location of what the general public would consider unusual breeding places, such as sewer catch basins or a flooded basement; discovery of a type of mosquito rare in the vicinity; explanation of the relief enjoyed by residents of some section as mosquito abatement begins to show results; special features of abatement work such as oiling of manholes and sewer catch basins; breaking down dams built by children across creeks where such dams stop the flow sufficiently to breed mosquitoes; appeals to residents to remove or correct backyard and garden mosquito breeding places; announcement that the abatement agency will supply, free of charge, mosquito fish (*Gambusia*) for ornamental garden ponds; and so on.

If possible, persuade the local papers to run occasional illustrated articles (stories of considerable length on the general style of a magazine article) explaining the various means of abating mosquitoes, the transmission of disease by mosquitoes, what work has been done, how the public can cooperate, and why mosquito abatement is desirable. Some papers do not go in for this style of article; in such cases it may be possible to get across the same information, although more briefly, in an editorial.

The stories should be mailed or preferably handed personally to the newspaper editor or to reporter friends. Be sure of these things: that the story will be of interest to a considerable number of the paper's readers (if you are digging ditches near both Newberg and Centerville, feature what is going on near Newberg in your story for the Newberg paper); that the story is written in language which can be understood by the average reader who is neither engineer nor entomologist; and that your lead, the opening sentence, will arouse the interest of the man casually perusing his paper.

This last point is of particular importance in the case of human interest stories. Feature the unusual angles of the story. For example, don't write an item this way:

> Mosquito abatement district employees are engaged today in oiling stagnant ponds in creek beds running through Centerville and in clearing the creek of underbrush. This work will kill off myriads of embryo mosquitoes now in the larval form but which would shortly emerge as adult mosquitoes on the wing and ready to bite.

Not too bad, but this is better:

> When hunting mosquitoes take an axe along, advises J. P. Smith, mosquito abatement district foreman. Smith and three laborers today are oiling stagnant ponds in creek beds running through Centerville, to kill millions of mosquito "wrigglers" before they emerge as adult mosquitoes on the wing and ready to bite.
>
> An oil spray gun brings death to the "wrigglers." The axe is useful in cutting through underbrush to reach the mosquito breeding pools.

Either story may be printed, but the first is not so likely to attract attention. The second story is not only more likely to be read but may interest newspaper subscribers sufficiently so that they will read the next item they see under a "mosquito" headline.

Where possible, interest an editor in taking pictures of some phase of abatement work. When a newspaper sends out a salaried cameraman his picture will usually reach print. However, if an editor cannot be so persuaded, take your own photographs. Arrange a scene showing some form of activity (don't take a still life picture of a ditch, however beautiful to your eyes that ditch may be); if feasible, place a pretty girl in the picture; avoid dark backgrounds; get everything you want in the picture as close together as possible; and take the photograph as close up as you can. The best of such pictures may be published.

Mosquito abatement agencies located in metropolitan areas can use to good advantage what are known as community or advertising newspapers. These are usually weekly papers, frequently distributed without cost to residents of a particular section of a city. The community newspaper editor is anxious to gather interesting news items and, because of their local appeal, these papers are closely read.

One word of warning: be sure that every item you offer an editor for publication presents factual information that should be of interest to a considerable number of his paper's readers. Then you will gain the willing cooperation of the editor because you will be helping his newspaper to give its readers all the news.

### Speeches

Service clubs, business men's clubs, women's clubs, schools, boy scout and girl scout troops, in fact any group that holds a meeting offers a possible audience for a talk on mosquito abatement.

Slides or motion pictures, particularly the latter, add interest to a talk, in the opinion of most club program chairmen and audiences, so that money spent for one or the other may be considered well spent. The pictures should show not only how mosquitoes breed, but what the local organization is doing to abate the pests. The cost of taking a few hundred feet of film is reasonable.

A number of excellent films, prepared for the purpose of training personnel in mosquito control work, have been prepared by the United States Army, United States Navy, United States Public Health Service, and by commercial firms (e.g., Disney). Eventually prints of such films may become available to civilians for either educational or training purposes.

Most organizations will be willing to listen to a talk by the publicity director. Some organizations may insist on hearing the superintendent or a prominent trustee or other official. And some large organizations may not be interested in mosquito abatement unless the subject is brought up incidentally during a talk by some prominent speaker on a broader subject such as public health. These larger groups, however, usually have sections interested in some particular field of study. A civic betterment section or a public health section, for example, would probably welcome a talk on mosquito abatement.

An announcement by letter that a mosquito abatement agency has a film and is willing to display it will probably draw a few responses. Usually it will be necessary to look up club program chairmen, school principals, and scoutmasters and sell them the idea of a mosquito abatement program.

The public schools provide a valuable field for educational talks, as school children are quite likely to act on a sound suggestion and really do something about preventing mosquito breeding around their homes. The study of insects is part of the curriculum of nearly every grammar school, junior high school, and high school, and teachers are usually glad to get an outside speaker on the subject of mosquitoes.

Many radio stations and sometimes radio advertisers feature a regular period devoted to lectures on local government or civic affairs. Prepare a talk and submit it to such a station or advertiser. If the talk is interestingly prepared you will probably get on the air.

When talking to school children emphasize the matter of cooperation with the mosquito abatement agency by finding and eliminating mosquito breeding places. Business men will be more interested in an exposition of the cost of mosquito abatement and the economic values derived from it. A social service club will be attracted by the relation of mosquitoes to public health. The speech must be directed to the natural interests of the audience.

Remember that most people assimilate new ideas with difficulty. *Don't talk more than half an hour; make a few important points, and make them very clearly; speak slowly, clearly, and in simple words; under no circumstances use technical terms if they can be avoided.*

Exhibits

Opportunity for effective use of an exhibit will probably come only after a mosquito abatement project is in operation. Just what is to be shown by an exhibit depends on how much money is available, what type of abatement work is of greatest importance locally, and where and how the exhibit is to be displayed.

One thing that always attracts attention is a jar or bowl of mosquito eggs, larvae, and pupae. The best exhibit is a large flat-sided museum jar with the top covered with cloth so that emerging adults will be retained. If mosquito fish are used to curtail mosquito breeding, exhibit the *Gambusia* next to the jar of larvae.

If drainage is the principal task, a model marsh illustrating various types of drainage would be appropriate. A working model, for example a salt marsh with rising and falling tidewater, is most effective—anything that moves attracts attention. If, however, the project is principally concerned with home-grown fresh-water mosquitoes, a backyard scene with a rain barrel, horse trough, tin cans, and lily pond in evidence, marked with signs pointing out these typical breeding places, will make an excellent object lesson, especially if each breeding place contains a few mosquito larvae. Models may be made by any firm engaged in that type of work, or you may find it more satisfactory and less expensive to build your own.

If malaria is important in the community, a diagram showing the life cycle of the plasmodium of malaria will be interesting (see Herms, *Medical Entomology*, 3d ed., New York, Macmillan, 1939, page 201). Somewhat similar diagrams can be made for other mosquito-transmitted diseases.

A panel of photographs depicting features of the work will attract attention. The photos should be enlarged to at least 5 by 8 inches (preferably larger) and well spaced. Charts showing annual costs of mosquito abatement per capita, per square mile, and per $100 assessed valuation in the local district and in other districts will be of interest.

Such public gatherings as flower shows, county fairs, and "open house" at the city hall or county court house offer opportunities for a mosquito abatement exhibit. Public schools furnish locations for displaying the exhibit. Local merchants may be persuaded to devote some space in their windows to a mosquito abatement exhibit in connection with a civic beautification or clean-up drive.

A well-designed exhibit attracts attention and offers the further advantage that interested citizens can be buttonholed and told all about the work.

### Informative pamphlets

A brief informative pamphlet or leaflet, topped with a striking heading and written in an interesting manner, is a most useful instrument for public education. Such pamphlets should be distributed during house-to-house inspections, at exhibits, and after public meetings where mosquito abatement has been discussed. Copies should be carried by field men engaged in searching for and abating local mosquito breeding places and distributed to persons they encounter in that work. The pamphlet, by acting as a sort of calling card, will also lend support to the employee's request for permission to inspect someone's property.

The pamphlet should tell: 1) why mosquitoes are undesirable—this is particularly important where malaria is prevalent; 2) how to avoid breeding mosquitoes; 3) whom to call on for relief when annoyed by mosquitoes; and 4) what, in general, the mosquito abatement agency is doing to eliminate mosquitoes.

A striking heading is important to ensure that the pamphlet will not immediately find its way into the wastebasket. This eventual end will be further delayed if the leaflet's contents are written in such a manner that the reader's interest is captured at the start, and he is induced to read the leaflet all the way through because of sustained interest.

Once again the particular conditions existing on a project will determine in part just how the pamphlet will read. On pages 91–96 is a form of leaflet which has been successfully used in a district having principally salt-marsh and non-malarial fresh-water mosquitoes. In a malarial area, the leaflet should be modified so that the essential facts as to malaria transmission by mosquitoes are featured. Other changes should be made according to local requirements as to mosquito species and conditions.

### District inspections

While a house-to-house inspection is primarily an attempt to locate and eliminate mosquito breeding places, it offers one of the best opportunities for educational work. Inspectors should be sent from door to door to examine each piece of property for possible mosquito breeding places. Wherever anyone is home the inspector should explain the purpose of his visit and give brief information as to how mosquito breeding may be prevented. Whether the occupant is at home or not, the inspector should leave a pamphlet which tells how to avoid breeding mosquitoes and gives a general idea of the purpose and work of the local district.

An excellent idea, though one which in practice has proven unexpectedly difficult, is to take a group of newspapermen, service club executives, or prominent leaders resident in the region for an auto tour to view particular phases of the work under way or completed.

The obvious virtue of a tour of inspection, at least on a project where extensive drainage has been required, is that it brings home clearly the real size of the task at hand. Mention that you have drained 1000, 5000, or even 10,000 acres of swampland means little or nothing to most people. But take a city man out into the country, get him out of the car, make him walk a mile or so across a marsh, and then assure him that he hasn't even begun to see what has been done, and he will be thoroughly convinced that mosquito abatement is not merely a simple job of spraying a little oil here and there.

### Advertising in theaters

In the smaller communities it will usually be possible to get the proprietor of the local theater to run a few mosquito lantern slides along with the local advertising slides. These slides may be pithy sentences calling for public cooperation in eliminating mosquito breeding places, or warning people of the danger of mosquitoes as carriers of disease. They may also be pictures of work being done, with explanatory titles on the slides.

### Essay contests

One certain way to arouse considerable public interest in mosquito abatement is to have an essay competition among the school children of the community. The subject of the essay may be: the mosquito, its life history and habits; or methods of mosquito abatement; or the damage malaria or other mosquito-transmitted disease does to a community. Small cash prizes may be offered for the best essays. The prizes should be donated by some prominent citizen or preferably by an organization like the chamber of commerce, the farm bureau, or a fraternal society.

The presentation of the prizes should be made with considerable ceremony in as public a manner as possible. The essay contest should also have considerable newspaper publicity and the winning essays should be published. Such a contest requires considerable work but is well worth while for the public interest it arouses.

### Use of the telephone

The telephone can be an excellent tool for increasing the effectiveness of control measures and for building public good will.

Telephone service should be listed at least twice in the directory, once under the name of the organization, and once under some caption beginning with the word *Mosquito;* for example *Mosquito Abatement District.* If there is a general listing of county or city departments, it should be listed also under such heading, if an official agency.

The object of such extra listings is to make it easy for any citizen to make a complaint or request assistance. Few people will go to any great effort to report the presence of mosquitoes and if they cannot find easily the number in the telephone book they will grumble and say that the mosquito men are inefficient or negligent in their work. As they will look either under the city or county offices, or for the word *mosquito,* the listing should appear at least in both places.

In taking telephone complaints, even if irascibly and forcefully presented, every effort should be made to impress upon the complainant that his cooperation in giving the information is welcomed and appreciated. He should be thanked for it. His name, telephone number, and address should be taken; and as soon as possible he should be informed what breeding was discovered, and what was done about it. He should also be asked to report in a few days if the infestation does not stop and also if he is bothered at any time in the future. If the abatement work is promptly and effectively done, the complainant will become a friend and advocate of the work.

It is probably desirable that the term *service request*,[1] or some similar term, be used in place of the term *complaint*.

The telephone can also be very useful in receiving reports from field men and giving them directions. This is especially true in large cities during the active breeding season. By having the field men call the office several times a day, it is possible to give them new complaints which will either save transportation expense or give quicker service. The promptness of service in particular will call forth public approval.

It is obvious that all relations with the public via the telephone should be conducted in courteous language and in a pleasant tone of voice. The expenditure of thought and effort on this item will yield surprising dividends in public good will.

### Public relations

Mosquito abatement is professional work of tremendous value to a mosquito-infested community. Unfortunately, to some people (particularly to newcomers in a community who perhaps never experienced the extreme annoyance inflicted by mosquitoes) the idea of an agency engaged in getting rid of mosquitoes may be ridiculous. Your educational work must overcome this impression. Newspaper publicity releases, speeches, and other forms of public education should be made as interesting as is possible and kept non-technical. However, avoid any freak publicity stunts that may make mosquito control appear to be something humorous.

It is important that all mosquito abatement workers keep in mind that they represent the abatement project to all persons with whom they come in contact. Discourteous employees will quickly undo the good that a program of education and publicity will accomplish. Conversely, a group of employees who are courteous, reasonable, and helpful in their dealings with the public are of the greatest assistance in maintaining satisfactory public relations.

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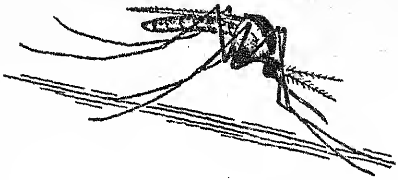
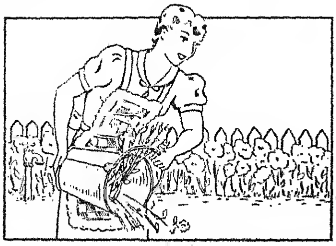
# Mosquitoes are Unnecessary



You don't have to suffer annoyance from irritating and sometimes dangerous mosquitoes. Most of the mosquitoes that formerly infested Alameda County are under control now. Those that you find today probably are breeding in your neighborhood. With your help these remaining pests can be subdued.

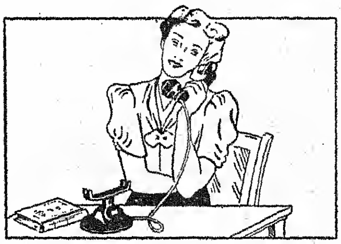
## How to Avoid Mosquitoes



1. Get rid of all standing water on your premises. Remove or dump tin cans, buckets, barrels, jars, vases, gourds, and any other receptacles that will hold water. Repair leaky plumbing and stopped-up eaves drains.

2. Be sure that your ornamental garden pond is stocked with goldfish or mosquito fish. (Either of these fish will eat any mosquito eggs that are deposited in the pond.) Mosquito fish can be secured from the Mosquito Abatement District without charge.

3. Kill mosquito larvae in water that cannot be removed (for example: seepage from springs, flooded basements, water tanks, and wells) by covering the water with a light film of fly spray or kerosene.



4. Advise the Mosquito Abatement District at once when you are bothered with mosquitoes. Phone GLencourt 4544 or write the District at the New Court House, Oakland. A trained employee will be sent to locate and abate the mosquito breeding.

The Alameda County Mosquito Abatement District controls mosquito breeding on 12,000 acres of marshland, along several hundred miles of creekbed, in 10,000 sewer catch basins, and in a great many other collections of standing water. *Your cooperation* is needed to wipe out "backyard" mosquito breeding. Mosquitoes are smart. They prefer hidden or partly concealed standing water in which to lay their eggs. Spare yourself annoyance by regularly making a careful inspection of your premises to make sure that you are not raising mosquitoes at home.

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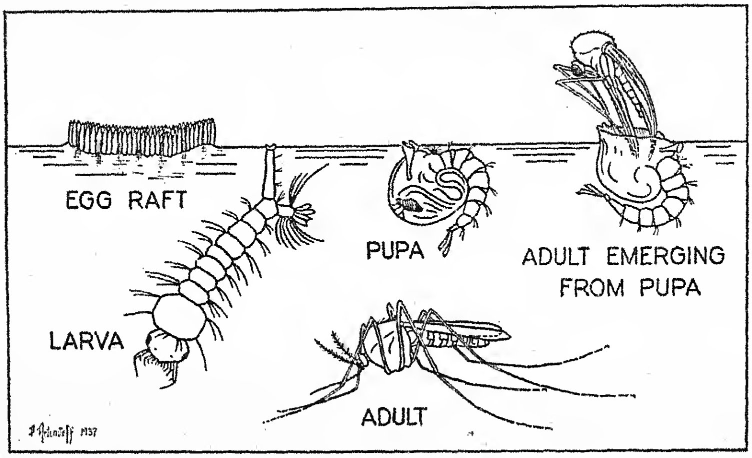
*Alameda County Mosquito Abatement District*

New Court House, Oakland — Telephone GLencourt 4544

# How Mosquitoes Breed

The several species of mosquitoes that must be combated here have different habits. Some bite in the daytime, some bite only at night. Some fly for many miles, others travel no farther than they must to find someone to bite. Two local species breed in salt water on tidal marshes; the remaining types develop in fresh water.

However, all species have this in common: MOSQUITOES BREED ONLY IN STANDING WATER. They never breed in grass, shrubbery, or vines, although the adult flying mosquitoes frequently rest there.




**Life History of the House Mosquito**

The common house mosquito, *Culex pipiens,* is today the most prevalent species. This insect bites at dusk and after dark. It is the mosquito that gets into your house, where its song is almost as annoying as its bite.

*Culex pipiens* lays several hundred eggs at a time in rafts. Out of the eggs hatch the larvae, popularly called "wrigglers." These turn into pupae, from which the adult winged mosquito emerges. Only the female mosquito bites. In warm weather, the process from egg to adult takes only seven to ten days.

# Mosquito Abatement Pays Dividends

People will not live where mosquitoes make life miserable. Many otherwise highly desirable sections of Alameda County used to be infested with mosquitoes. Alameda County residents formed the Mosquito Abatement District to correct this situation.

Now that most of the mosquitoes are subdued, the East Bay today is experiencing an unhandicapped expansion of home building, which is bringing with it increased population and added payrolls that benefit the entire community.

Improved public health, opportunity for full use and enjoyment of golf courses, tennis courts, swimming pools, and all other outdoor recreational facilities, and increased labor efficiency are among other advantages produced by an efficient program of mosquito control.



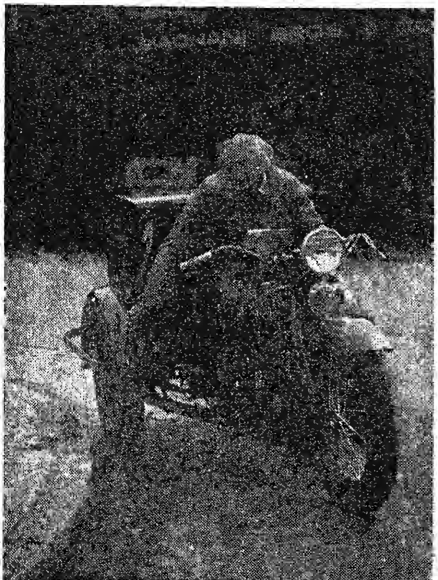
Figure 8. Leaflet for

# *How Alameda County is Kept Free of Mosquitoes*

Alameda County's present relatively mosquito-free condition is not accidental It is due to work that is being done constantly by the Alameda County Mosquito Abatement District. This is an agency of the government made up of the cities of Oakland, Berkeley, Alameda, Piedmont, Emeryville, San Leandro, and Hayward, and Eden and Washington townships.

Nine out of ten mosquitoes that used to annoy residents of the District were of two particularly vicious species that develop in salt water on tidal marshes along the shores of the bay. These marsh mosquitoes are migratory. Hordes of them used to leave the marshes and fly inland throughout the District, traveling from 10 to 50 miles and biting those they encountered on their flights. Many sections of Alameda County used to be so badly infested with these migratory insects during summer and fall months that residents hardly dared to step out-of-doors.

Today you will rarely see a marsh mosquito in the East Bay. This is because the Mosquito Abatement District has drained more than 12,000 acres of mosquito breeding marsh—an area greater than the combined areas of Berkeley, Emeryville, and Piedmont. Continuous maintenance of drainage systems is required to keep the marsh mosquitoes subdued. Each year District employees must clean out silt, marsh grass, weeds, and junk from more than 120 miles of drain ditch, repair levees and tide gates, and perform other maintenance work.



**Motorcycle Equipment Is Used to Oil 10,000 Catch Basins**

Light oils and larvicides, applied with spray guns, are the principal weapons against the several species of fresh water mosquitoes found locally. In the cities, motorcycle equipment is used to oil water standing in more than 10,000 sewer catch basins (where gutter water runs into the sewers). 3,700 public utility underground street vaults ("man-holes"), several hundred miles of creekbed, roadside ditch, and dairy drains, and more than 3,000 cesspools and septic tanks are among other fresh water mosquito breeding places that must be controlled by regular oiling.

# *Do You Know?*

"MOSQUITO FISH" eat mosquito eggs and "wrigglers" and thus will keep your garden pond from becoming a mosquito breeding place, but the fish will not leap into the air to catch mosquitoes that happen to be flying by. If your pond is already stocked with goldfish you do not need "mosquito fish," as both do the same job. You do not have to feed "mosquito fish."

CLUBS AND ORGANIZATIONS may arrange to hear an interesting talk on mosquitoes and mosquito control by phoning or writing the Mosquito Abatement District. A two-reel motion picture of the District's work is also available for groups of 100 or more.

HOW LONG A MOSQUITO LIVES varies according to the species and to what luck the insect has in avoiding sudden death at the hands of its natural enemies, including man. However, in Alameda County under normal conditions the several species of fresh water mosquitoes appear to live about one to two weeks, while the marsh mosquitoes live from two to four weeks.

EDEN TOWNSHIP residents who are being bothered with mosquitoes or who want "mosquito fish" should advise District Foreman L. P. Mapes, of 1391 "B" Street, Hayward, phone Hayward 1046. In WASHINGTON TOWNSHIP, advise District Foreman Roland Bendel at Decoto, phone Niles 128-W.

ALL OF ALAMEDA COUNTY, with the exception of the city of Albany, and Murray and Pleasanton Townships, is within the Alameda County Mosquito Abatement District. The District has an area of 320 square miles (including approximately 60 square miles of marsh) and an estimated population of 460,000.

TAXATION PROVIDES FUNDS for the mosquito control work done in Alameda County. Except for the first year of operation (1931), when much original heavy construction had to be done, the Mosquito Abatement District tax has never exceeded 1c per $100 assessed valuation. This has amounted on the average to from 1/300th to 1/600th part of the total city and county tax rates.

THERE ARE 24 mosquito abatement districts in California. Nine districts are in counties adjacent to San Francisco Bay.

NO DISEASES ARE KNOWN to be carried by mosquitoes encountered in Alameda County, although the hordes of mosquitoes present before control operations began occasionally made some persons ill from the mildly poisonous effects of numerous mosquito bites. Malaria-carrying species never were numerous in this vicinity, and the few formerly present have been virtually wiped out.

GREECE, ALBANIA, ARGENTINA, and CHINA are among foreign countries which have sent engineers to Alameda County to study the successful mosquito control methods employed here.

Figure 8. Leaflet for public information (page 4)

## HOW TO DISTINGUISH THE PRINCIPAL SPECIES OF MOSQUITOES IN ALAMEDA COUNTY

| | Aedes dorsalis | Aedes squamiger | Culex pipiens | Culex tarsalis | Theobaldia incidens | Anopheles pseudo-punctipennis |
|---|---|---|---|---|---|---|
| COLOR | Tan | Gray | Brown | Brown | Brownish gray | Dark gray |
| BREEDING PLACES | Brackish water-salt marshes or rice fields | Rain water on salt marshes | Fresh or foul water in containers, cesspools, etc. | Fresh water swamps, dairy drains, etc. | Shady fresh water pools | Clean fresh water pools |
| BITING HABITS | Day and dusk | Day and dusk | Night | Night and dusk | Night and dusk | Night and dusk |
| FLIGHT RANGE | 10 to 30 miles | 40 to 50 miles | About 1000 feet | About one mile | About one mile | Perhaps one mile |
| POSITION WHEN BITING | ← Body is parallel to surface → | | | | | Body at distinct angle to surface |
| EGGS | Laid in or on marsh mud | Laid in or on marsh mud | Laid in clumps on water surface | Laid in clumps on water surface | Laid in clumps on water surface | Laid singly on water surface |
| LARVAE | ← Body hangs head down at angle to surface → | | | | | Body lies parallel to water surface |
| LARVAL FEEDING HABITS | ← Bottom feeders → | | | | | Feed at water surface |
| PUPAE | ← Look like fat commas → | | | | | |
| PALPI | ← Short - less than ½ length of proboscis → | | | | | Long - as long as proboscis |
| WINGS | ← Not spotted → | | | | Spotted | Spotted |
| LEGS | Slightly white banded | Distinctly white banded | | White banded | | |
| ABDOMEN | Pointed | Pointed | Blunt | Blunt | Blunt | |

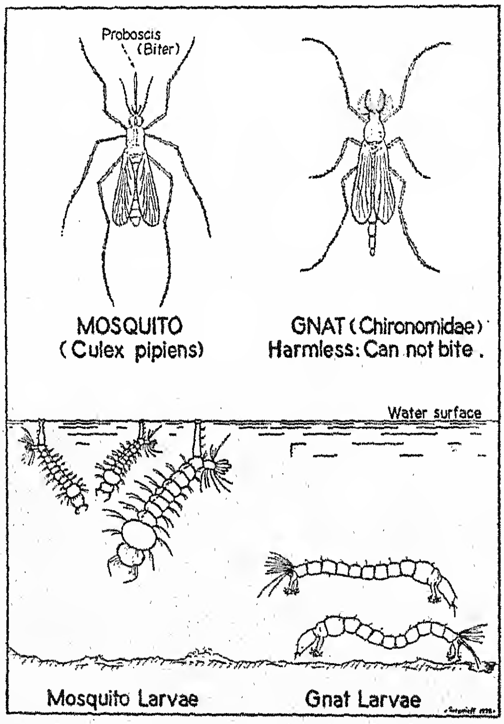
FIGURE 8. LEAFLET FOR PUBLIC INFORMATION (PAGE 5)

# Insects Sometimes Mistaken for Mosquitoes

In general, if the insect doesn't bite, it isn't a mosquito.

Chief among local insects which look like mosquitoes are the Chironomid gnats, or midges. Midges sometimes are so numerous that they completely cover screen doors and windows. Fortunately, they cannot bite, and they do not carry any disease. *There is no practical way known to control gnats.*

The mosquito has a sharp, lance-like proboscis with which it bites.




Midges have no biting instrument. The bushy antennae (feelers) on the head of a midge also help to distinguish it from a mosquito.

Mosquito larvae obligingly come to the water surface to get air, and can be poisoned with oil which gets into their breathing tubes.

Gnat larvae breathe through gills and remain at the bottom until the moment when they are ready to emerge as winged insects.

Complete drainage would halt the breeding of gnats, but this is impractical because they breed in lakes, reservoirs, flood waters, and even in moving streams. Residents can kill adult gnats in their homes with fly spray.

Tipulidae, popularly known as crane flies, mosquito hawks, and sometimes as "daddy long-legs" are also occasionally mistaken for mosquitoes. Tipulidae are large and slow moving, and are entirely harmless.

The Mosquito Abatement District has only a small force of employees and must devote all of its efforts to the control of mosquitoes. The District cannot take care of gnats, bees, yellowjackets, fleas, ants, termites, spiders, or moths. Please advise the District at once when you are bothered with mosquitoes—but please make sure they *are mosquitoes.*

FIGURE 8. LEAFLET FOR PUBLIC INFORMATION (PAGE 6)

## VI

# FINDING MOSQUITO BREEDING PLACES

THE FUNDAMENTAL requisite of mosquito abatement is the elimination, or at least the reduction, of mosquito production. This entails primarily the prevention of mosquito breeding by elimination of breeding places or by alteration of ecological conditions so as to make such places unsuitable for breeding; and secondarily the destruction of mosquito larvae and pupae. Before either the primary or secondary aims can be accomplished it is necessary to locate the places which contain the aquatic developmental stages of these insects. There are four stages in the development or metamorphosis of mosquitoes: the eggs, the larvae or "wrigglers," the pupae, and the adults. The larvae and pupae must have water for their development, and therefore these two stages are the points of greatest vulnerability. Finding the breeding places is thus the first step in the attack upon any and all kinds of mosquitoes.

### *BREEDING PLACES PECULIAR TO SPECIES*

Finding the breeding places is greatly facilitated by the identification of the species which are prevalent in a region or the cause of a specific complaint. The various species choose different types of breeding places which may be broadly grouped in ecological associations,[1] though within such groupings there may be marked variations. A sound basis of entomological knowledge, not only of species identification but also of the biology and ecology of mosquitoes, is most helpful to a mosquito "detective."

In an area which has been under control or observation for some time, so that the species of local mosquitoes are well known, the identity of a particular culprit and the probable location of its breeding place can often be inferred from the wording of complaints that come to a mosquito abatement office. The usual complaint runs almost in stereotyped form. It is either: "The mosquitoes are simply terrible—I can't get a wink of sleep," or "The mosquitoes are simply terrible—I can't water the lawn (or work in the garden) without getting bitten by thousands of the pests."

The experienced entomologist at once recognizes that almost certainly two distinct species are involved in these complaints. One is evidently a night-flying, domestic, fresh-water breeding mosquito, such as *Culex pipiens, C. quinquefasciatus,* or a mosquito of similar biting habits. The other is a day-biting mosquito, most probably one of the salt-marsh group if within reasonable flight distance of a bay or estuary, otherwise some species of fresh-water breeding, day-biting mosquito, such as *Aedes vexans.* When the species is known, the type of breeding place which must be looked for is also known within certain limits. If it is certain that a salt-marsh mosquito, such as *Aedes dorsalis* or *A. sollicitans,* is the species complained of, it is obviously useless to search for its breeding place in fresh-water containers or lily ponds in the immediate vicinity. In such a case the salt marshes in the direction of the then or recently prevailing winds must be searched, though even that may be a useless gesture *at that time.* An examination of captured salt-marsh mosquitoes may yield some clue. If they are well clothed with wing scales, they have probably come from near-by marshes; but if the wing scales are scanty for that species, the insect has probably had a long, hard journey from distant marshes. Thirty or forty miles is not an uncommon range (see Figure 9) for some species of salt-marsh mosquitoes, especially *Aedes squamiger;* some flights of over fifty miles have been observed; probably the longest flight[2] that has been properly documented is that of a swarm of *Aedes sollicitans* which reached the steamer *Cristobal Colon* while 110 miles off Cape Hatteras on September 11, 1927.

On the other hand, if it is a night-biting, indoor mosquito that is complained of, it is probably one of the fresh-water breeding, domestic types, and the source of breeding is probably in the near vicinity, usually, though not necessarily, within a few hundred feet. However, here a knowledge of the species of mosquito will save time and effort in locating the breeding place. If it is *Culex pipiens* we would look for local lily ponds, buckets, barrels, tin cans, cesspools, street vaults, catch basins, and similar collections of water. But if it is *Aedes varipalpus,* usually a day biter, look for water-filled holes in trees which are their natural breeding places.

In searching for the breeding places of the common fresh-water species, care should be taken not to be misled by certain widely held notions as to the flight range of mosquitoes. It is commonly said that

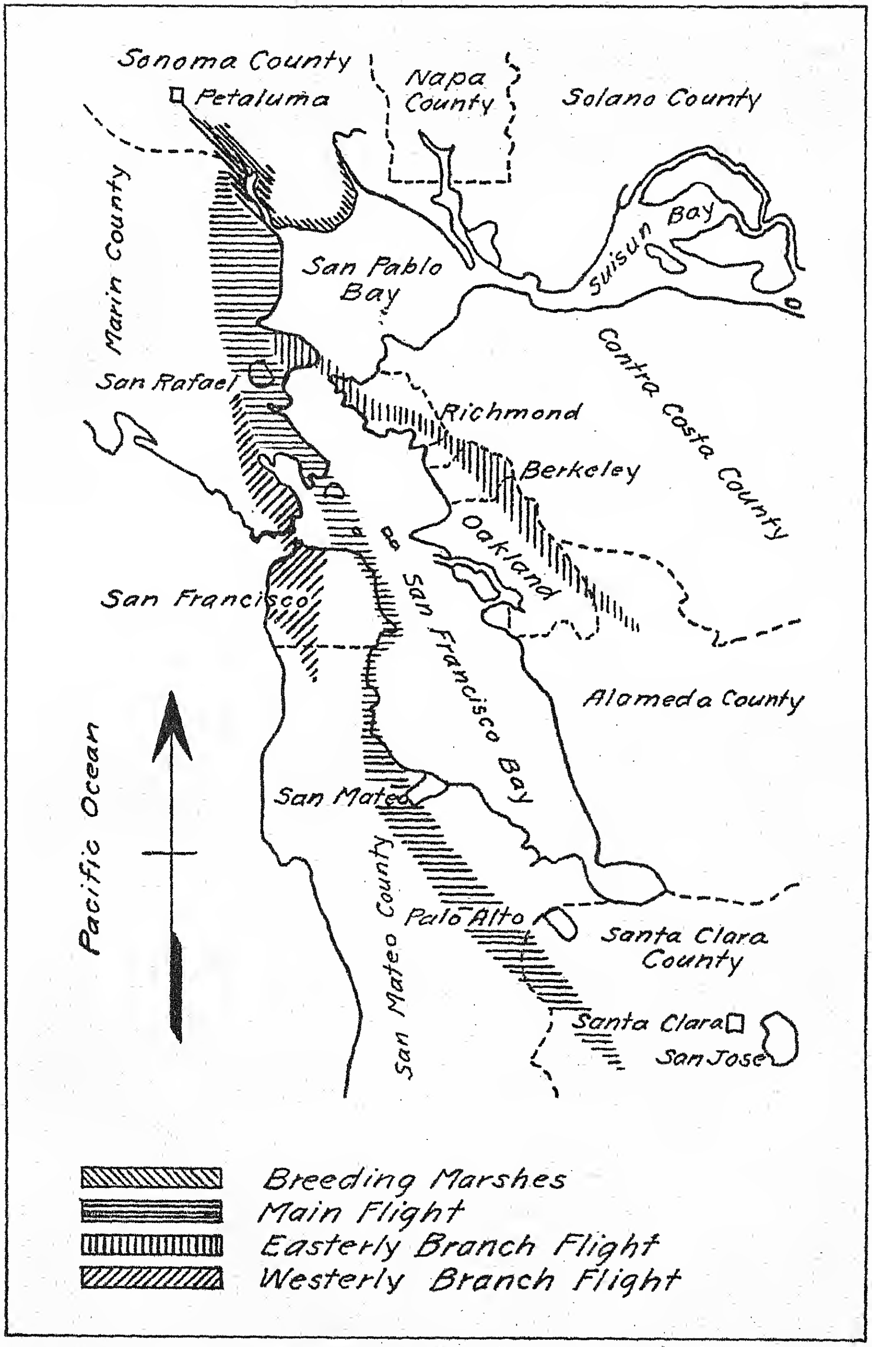



Figure 9. Map showing the annual migration of *Aedes squamiger* in the San Francisco Bay region

the anopheline species and the house or domestic types of culicines do not travel more than a few hundred feet from their breeding places. That is only partially true. The travel habits of many of our well-known species are imperfectly understood, but it appears probable that the distance and direction of travel depend upon several factors, among the most important being the distance between the place of breeding and the place where warm-blooded animals (including man) are in sufficient numbers to furnish an adequate food supply. If an adequate food supply is close to the breeding places, the mosquitoes probably will not travel far; but if there are no warm-blooded animals adjacent to the breeding places or if there are inadequate numbers of animals, it appears probable that they will travel considerable distances in order to reach an adequate food supply.

The relationship of breeding place and food supply has not been adequately studied; it may explain many uncertainties in the travel habits of mosquitoes. It is even possible that it may explain, at least in part, the great migrations of salt-marsh mosquitoes, as it is evidently impossible that the warm-blooded animals on or adjacent to salt marshes are sufficient to feed more than a small percentage of the enormous mosquito output of such marshes.

Clarke[3] has made some very interesting studies on the flight range of *Aedes vexans* and *Culex pipiens*, using a starch-dye staining technique developed by him,[4] and determining the distance of travel and approximately the rate of progression by captures with the New Jersey type light traps. He found that the males of *Aedes vexans* accompanied the females on migration, which had been observed to some extent previously, but he also found that a considerable number of male *Culex pipiens* accompanied the females, and that both male and female *Culex pipiens* migrated much further (about nine and one-half miles) than has been heretofore recorded or considered to be possible for this species. Clarke's experiment should be checked by similar studies in other areas, and in particular it should be determined whether the variety of *Culex pipiens* observed is the comparatively non-biting *Culex pipiens pipiens*, which breeds in relatively clear water somewhat open to sunlight, or the more strictly domestic, biting variety, *Culex pipiens molestus*, which breeds by preference in foul water, almost always well covered or at least heavily shaded.

Another thing to take into account is the time of the year in relation to the migratory habits of certain species. For example, *Anopheles maculipennis freeborni*, in California, goes on a dispersal flight twice a year, in the spring (about February 20) and in the autumn (early October), when it apparently disperses radially for many miles from the breeding places.[5] Under such conditions it would be foolish to confine inspections to the close vicinity of the place where the mosquitoes are found.

Under some circumstances it would be entirely useless to look for the breeding places of a particular mosquito at the time the complaint is received. For example, *Aedes communis* or *A. intrudens* adults caught in August would indicate the futility of seeking their breeding place *at that time*, as these species are single brooded and are hatched in the spring. No larvae or pupae of either species could be found at that time of the year.

Obviously, in view of the foregoing, a knowledge of the species of mosquitoes involved in a complaint is necessary for two reasons: a) to ensure effective abatement; b) to prevent useless work and expense in abatement.

In preliminary investigations of a region in which mosquito abatement is proposed, it is also necessary that the several species of prevalent mosquitoes must be determined. Upon the species depends to a great extent the types of abatement procedures which will be adopted, the area which must be included for effective work, and the cost of the work. The species present, considered in relation to their environment, may also determine whether a generalized attack on all species of mosquitoes will be attempted or efforts limited to one or a few species of greatest importance (species sanitation).

### *CAPTURING MOSQUITOES FOR SPECIES IDENTIFICATION*

In searching for adult mosquitoes for species determination, a few simple rules should be observed. Both male and female specimens should be collected. During the day few adult mosquitoes are active and so must be found in their hiding places. Generally most species will be found in dark, cool, and moist places, under bridges in rural areas, and under houses and in basements and cellars in towns. Within houses, the adults may usually be found hiding behind pictures, in draperies, closets, and the like. In rural areas, the outdoor privy is a favorite hiding place for mosquitoes. An electric flashlight is very useful in the search, as the light beam can be flashed along the ceiling and into the dark corners to locate the insects.

During the middle of the day, some species, such as *Aedes dorsalis*, hide in shrubbery and usually can be found by shaking the bushes. Some species will attack humans during the day in the shade and require no special efforts to locate.

### Simple devices

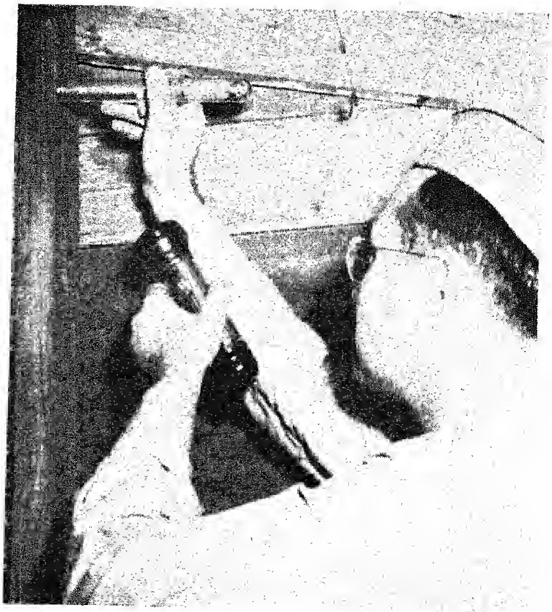
A small net on a handle is useful in collecting specimens, but a small glass vial, straight-sided and without a lip, is usually all that is necessary. The vial can be slipped over the mosquito while at rest. The advantage of the glass vial is that less damage is apt to be done to the mosquito than if swept into a net. A cyanide bottle is a useful collecting device. This is made by pouring about one-inch depth of wet plaster of Paris over a small quantity of sodium or potassium cyanide in the bottom of the vial, and covering it with a circular disk of blotting paper. A similar vial[6] using chloroform-saturated rubber bands or cotton is a substitute for the cyanide bottle. In grass, sweeping with a collecting net may be the only successful method for collecting specimens.

If it is desired to catch the mosquitoes and keep them alive, the sucking tube is the best device. This is made of a piece of three-quarter-inch diameter glass tubing about one foot long, drawn abruptly down to a diameter of about one-fourth inch at one end. To this end attach about two feet of quarter-inch rubber tubing. Fit a piece of fine wire gauze into the small end of the glass tube to prevent specimens being sucked into the rubber tube. In operation, the open end of the rubber tube is inserted into the mouth, and the open end of the glass tube is placed near the mosquito; a sharp suck of the breath pulls the mosquito into the tube. The palm of the left hand should be quickly placed over the open end of the glass tube, and the mosquito examined and approximately identified. If it is to be kept, it can then be blown into a collecting bottle.

### Mosquito traps

There are several forms of traps for catching adult mosquitoes for identification or for other purposes. Provided the usefulness and limitations of each type are understood, these traps can give infor-

Figure 10. Capturing adult mosquitoes with a flashlight and chloroform tube



*Courtesy U. S. Public Health Service*

*Courtesy U. S. Public Health Service*

Figure 11. Dipping for mosquito larvae

Figure 12. Searching for mosquito larvae in stream-side pools

Figure 13. Organic debris, or floatage, which protects mosquito larvae, particularly *Anopheles quadrimaculatus*, from their natural enemies

mation as to the mosquito species present in an area, their travel habits, and other data.

In searching for adult mosquitoes, the simplest procedure is to look for them in natural roosting or hiding places during the day. The habits of each species will determine where they will be found; for example, *Haemogogus capricornii* retires to palm tops during the day. But the usual daytime refuges are under small bridges, in culverts, in heavy shrubbery, or in barns, pigpens, and houses, cellars, closets, and the like. Traps can be made to simulate such natural roosting places. Inverted barrels, kegs,[7] or boxes, properly placed, will act as traps for such species as *Anopheles quadrimaculatus*.

Magoon[8] in Jamaica, G. C. Payne in Haiti, and W. C. Earle in Puerto Rico made use of portable stable traps, which presumably can be expected to attract relatively more of the zoophilous species than of the anthropophilous species. In some cases in Africa trap houses have been used, with living natives as the bait. Metz[9] in 1918–19 in Florida, observing that *Anopheles* were strongly attracted by swine, experimented with portable pigpen traps, and found that their use apparently greatly reduced the numbers of *Anopheles* (*A. quadrimaculatus* and *A. crucians*) in near-by buildings. Like Metz, we also found that covered pigpens in the vicinity of houses are excellent mosquito-catching stations, and will usually present numerous specimens of all the mosquito species in that locality, especially the anophelines.

Large animals, such as horses and cows, can frequently be used as collecting posts, using a sucking tube or a chloroform tube as a catching device. Similarly, a man remaining stationary may also be used as a collection point. However, some form of light trap has been generally used as an artificial attractant and catching device.

During the early days of construction of the Panama Canal, LePrince made use of mosquito traps to assist in determining prevalent species of mosquitoes and in studying their habits and to supplement hand-catching control work in barracks and houses.

LePrince's observations are of interest in many ways. He noticed that culicine mosquitoes would be attracted to strong lights such as electric arcs, but that the Isthmian anophelines found strong lights repulsive. He found, by trial with an experimental house at Corozal,[10] that increase or decrease of electric light in buildings apparently made little difference in the number of anophelines entering; if the lights were increased, the culicines entering increased; if a building was empty, with or without lights, only an occasional *Anopheles* entered; but when one or two men slept in the building the *Anopheles* crowded through small openings into the building and bit the men, whether the building was lighted or not.

In experimenting with traps LePrince (*loc. cit.*, p. 216) found that traps must be attached to windows on the lee side of buildings to catch anophelines, and that if two screened buildings, one occupied and one vacant, were furnished with traps, no *Anopheles* entered the traps attached to the vacant building.

These observations of LePrince can be easily confirmed by simple experiments, and by observation of mosquitoes. We have found that *Anopheles maculipennis freeborni* is deterred from attacking by a strong light, but will attack freely after dark, both indoors and outdoors, either in a subdued light or in the dark. Within houses *Culex pipiens* will usually not attack in strongly lighted rooms, at any hour of the night, but will attack promptly when the lights are extinguished. It is a matter of common observation that most *Aedes* species are primarily crepuscular (twilight) and daytime biters, and seldom attack in complete darkness.

Obviously, therefore, the reactions to light of the various genera, and to some extent species, of mosquitoes vary considerably, and may greatly affect quantitative catches by light traps. Intensity and color of light may also make appreciable differences as attractants or repellants of mosquitoes.

Headlee[11] found that both the intensity and the frequency of radiant energy (light) have a marked effect on the attraction or repulsion of mosquitoes. On comparative tests with several types of light, using a 25-watt frosted electric globe as a base, he found the relative attractive power of different colored lights, corrected to the same basis of radiant energy, was as follows:

| | |
|---|---|
| White | 1.0 |
| Red | 6.1 |
| Green-yellow | 12.3 |
| Blue | 21.5 |

Headlee's experiments apparently took no cognizance of increased or decreased intensity of colored lights in relation to relative attraction for each light, and gave no analysis of effect upon widely varying species of mosquitoes.

Nuttall,[12] experimenting with unilluminated boxes lined with colored cloth and using *Anopheles maculipennis*, found a decided preference for dark blue as compared with greens, yellows, reds, and white. But LePrince (personal communication), working with *Anopheles quadrimaculatus*, found no color preference for roosting surfaces.

One of us (W.B.H.) has for many years conducted experiments on the effect of monochromatic lights upon many types of insects, including a few species of mosquitoes (for example, *Aedes dorsalis*). These experiments are still under way, but they indicate not only decided species preference for certain colors of light, but also that a color which will relatively attract one species will relatively repel another species.

Combining these various observations and admitting that there are great gaps in our information as to both the light reactions of most species of mosquitoes and other stimuli which attract or repel them, we seem to be justified in concluding that the use of light traps, which has in recent years been widespread as a method of sampling mosquito populations in an area and determining relative prevalence of various species, may give information that is erroneous or inadequate. It is possible that light traps would attract a relatively large proportion of the *Aedes* species in an area, and a relatively small number of *Culex* and *Anopheles*.

In an endeavor to increase the attractive and catching capacity of light traps, several devices have been used. In 1928 Herms and Burgess[13] developed a light trap with a suction fan, to increase the catch of strongly phototropic positive gnats [*Chaoboris astictopus* (= *C. lacustrus*)]. Recently it has been determined that carbon dioxide is an attractant to mosquitoes, and Reeves and Hammon[14] constructed a trap successfully using carbon dioxide (dry ice), a light, and a fan. The entire equipment, however, is rather cumbersome.

The type of light trap which has been most widely used in the United States is known as the New Jersey light trap.[15, 16, 17, 18] In some localities the users of these traps appear to be well satisfied with their performance; others, such as Huffaker,[19, 20] Hart,[21] Mulrennan,[6] and Huffaker and Back,[27] have called attention to relative discrepancies between the numbers of various species caught by the light traps and the probable relative numbers of the several species as determined by other methods. The studies of Huffaker and Back[27] are particularly informative. They conclude that

> A consideration of the empirical data as well as purely theoretical concepts has convinced the writers that the New Jersey mosquito trap does not catch a representative sample of a mixed mosquito population. Different species may be attracted in different degrees, depending upon the prevailing conditions and the species.

Both Mulrennan[6] and Bradley[22] call attention to the inadequacy of light traps in measuring the density of *Anopheles quadrimaculatus*, and Jones[23] calls attention to the discrepancies between *A. quadrimaculatus* production and the catches of this species in light traps.

The placement of mosquito traps will change their effectiveness in capturing mosquitoes. There is still much to be learned about trap placement, particularly with reference to capture of different species, and as indices or guides to the location of production points. In general, traps should be placed in sheltered locations, protected against wind; they should be several feet above ground and away from competing lights, such as street lights; they should also be protected against being tampered with by curious or malicious persons; and should be conveniently accessible.

The nightly catches in traps must be collected daily and marked for identification, the trap serviced and a new collecting bag or box placed, and the catch brought to the laboratory. Here an entomologist first separates the mosquitoes from other insects (usually the mosquitoes are a small minority of the total catch); then the mosquitoes are separated into groups, such as *Aedes*, *Culex*, *Anopheles*, *Psorophora*, and so forth, and finally separated into species, counted, and recorded.

A number of mosquito abatement agencies have used traps as a means of gauging the relative prevalence of mosquitoes during a season or from year to year. If all other conditions remained constant, traps might give a relative picture of the prevalence of some species, but the other variables such as temperature, wind, humidity, and so forth, are not constant and therefore the results of such comparisons should not be too literally depended upon.

Covell[24] lists and describes a number of different types of mosquito traps, ranging from very simple to rather complex devices, most of which have been used in the tropics.

### Capturing mosquito larvae

Mosquito larvae and pupae are searched for not only to determine the production places of mosquitoes, so that control measures may be applied to them, but also to determine the breeding places of the important species in cases where a selective attack (species sanitation) is to be made upon a disease vector or pest. Inspections are also made to determine the effectiveness of control measures, and collections are made for purposes of identification and classification.

Inspections and collections may be general, to locate all types of breeding, or specific, to locate only the breeding places of a particular species against which selective control is to be applied. For either type, a reasonable knowledge of the breeding habits of mosquitoes is necessary.

Inspections for and collections of mosquito larvae should be made thoroughly and systematically, and properly recorded on forms, preferably on a single card or sheet for each collection point. The point should be accurately located on an inspection map by serial number or other designation, the corresponding number being placed on the record and on the sample collected. Also to be recorded are the type of breeding place (swamp, pool, pond, hoofprint, stream, tree hole, bromeliad); presence or absence of sunlight; whether water is fresh or brackish; presence of floatage, emergent vegetation, and the like; weather conditions; average number of larvae per dip; and any other pertinent information.

If field identifications are made at the time of collection, these should also be entered on the record form.

In making larval inspections and collections in a new area it is desirable first to size up the lay of the land and pick out the locations where breeding water most probably occurs. Upon reaching the breeding water, there should not be too much hurry to start collecting specimens; the water surface should be observed to locate areas where larvae appear to be most numerous and easy to get at, and to determine roughly what types (such as anophelines or culicines) are present and whether the species segregate or intermingle. The environmental conditions should be recorded and then the actual collection made.

A common white enamel dipper, having a top diameter of from four to six inches, and a depth of two to three inches, with a tubular handle, is the most useful tool for collecting larvae and pupae. A wood extension handle three to four feet long is helpful in reaching places which are difficult to get at, but the dipper can ordinarily be used without the handle. A small kitchen strainer made of fine metal gauze is occasionally a helpful tool.

It is frequently necessary to put on rubber boots and wade out into an area in order to obtain representative collections.

Two types of dips may be used: 1) a sweeping motion with the dipper held at an angle and with the lip just below the water surface; 2) plunging the dipper directly down into the water, and promptly withdrawing it. Each must be done quickly, and a little practice is necessary to get good results.

If there is much surface floatage, algae mats, or floating aquatic plants, these should be removed or brushed aside before attempting to dip (note: *Anopheles* larvae may be found in algae mats). In the presence of reeds, tules, rice, and other emergent vegetation, it may be necessary to push the growths aside, pull them out, or cut them down to furnish a clear area for dipping. In some shallow pools muddying the water by stirring up the bottom may help in causing the larvae to stand out more visibly against the muddy water background and to come to the surface more promptly.

If the larvae and pupae are frightened to the bottom by a heavy tread or a shadow cast on the surface, it will be necessary to wait quietly for a few moments after getting into position, until they return to the water surface, before making a dip.

In collecting from tree holes either a glass tube with a rubber bulb aspirator on the end, or a length of rubber tubing (one-fourth or three-eighths inch internal diameter) operated as a siphon, may be used to get the water and larvae out of the holes. A pail is often useful in such cases, as we have siphoned over five gallons out of some tree holes.

In collecting from bromeliads,[6] it may be better to cut the plant from the tree, lower it in a vertical position to the ground, using a rope, and then invert it carefully over a tub to collect the water and larvae.

In collecting for *Mansonia* which attaches itself to hollow-stemmed grasses below the water surface, it will be necessary to dig up or pull up such grasses and place them in a pail or tub of water in order to search for the larvae.

As the breeding places are found they can be marked for future reference, or for the control units, either by a conspicuously painted tall stake or by a tall stake with a colored flag. When the control work is applied, a different colored stake or flag may be substituted.

When the catch is obtained it may be examined in the dipper, and the larvae approximately identified. If the catch is to be sent to a laboratory for identification, large debris should be removed, the dipper tapped sharply to drive the larvae to the bottom, the upper water poured off carefully, and the remaining water with the larvae transferred to the collection bottle. Another method is to use an ordinary medicine dropper, with the narrow point cut off to enlarge the opening; the sharp edges should be rounded by fusing in a flame.

If the water is very foul or muddy, it may be poured through a small strainer, the dipper refilled with clean water, the strainer placed therein, and the larvae allowed to swim off.

For sending samples of larvae and pupae to the laboratory, ordinary wide-mouthed eight-ounce bottles fitted with screw caps or corks are satisfactory. Special shipping bottles with a short length of glass tube through the cork, projecting both inside and outside, have been used successfully. Sample bottles should be kept upright in partitioned fiber or wood boxes for transportation. In hot weather it is better to ship them on ice in a metal container such as a small automobile ice chest.[6]

Collections of larvae and pupae may be carried on over a large area if a general survey is being made, or may be confined to a limited area if a control project to protect only a definite locality is involved. They may be a part of an initial survey to determine what species are present and where they breed, or they may be a part of control surveys to check on the progress and effectiveness of the abatement work.

COLLECTING MOSQUITO EGGS

*Culex* eggs, which are laid in conspicuous masses (egg rafts) which look much like specks of soot floating on the water, are easily found and collected. *Anopheles* eggs are difficult to find in nature, as they are laid singly on the water surface.

The eggs of most *Aedes* species are laid singly on moist surfaces in places which may later become covered with water. On salt marshes the eggs are laid on the soil surface, frequently in cracks, or on marsh vegetation near the ground surface. Bradley and Travis[25] have developed a technique of soil sampling to determine the distribution and relative numbers of *Aedes* eggs on marshes. They used as a sampling device a sheet metal ring, 3.2 inches in diameter and one inch wide, mounted by metal strips on the end of a three-foot hoe handle. The area of the sampler is eight square inches. This is forced into the marsh surface and the enclosed soil is cut off with a sharp edged trowel and lifted out.

Samples are taken at suitable points on parallel lines laid out across the marsh. In general it was found that eggs were more numerous at the tops of the hummocks.

Samples are taken to the laboratory, placed in glass jars and immersed in water. The number of larvae hatching in twenty-four hours is counted.

It might be more convenient for calculations of mosquito output on an area basis to use a ring 4.28 inches in diameter (inside) which has an area of one-tenth square foot. Instead of flooding the samples to hatch the larvae, the number of eggs in the sample can be counted directly by drying and pulverizing the sample, and screening it between thirty-mesh and fifty-mesh screens. The eggs will be retained on the fifty-mesh screen and can be easily counted under a low power microscope.[26]

## *ORGANIZED INSPECTIONS*

Inspections for locating mosquito breeding places are usually of four kinds:

1. Preliminary survey of a region to determine the general location and extent of breeding places
2. District inspection when the abatement project is launched

3. Inspections upon complaint of mosquito prevalence
4. Follow-up inspections

### Preliminary surveys

The need for a general survey of the region, preliminary to the organization of a mosquito abatement project, was pointed out in CHAPTER IV. Such a survey should be conducted by an experienced entomologist who will be able to identify the species of mosquitoes prevalent in the region, direct the search for their breeding places, determine roughly the extent of both marsh and domestic breeding, and advise on the specific measures for their abatement.

The extent of territory to be included in the project and the abatement procedures to be adopted depend to a great extent upon the species of mosquitoes in the region. If salt-marsh mosquitoes are concerned, the area included, the cost of the work, and the abatement methods will differ greatly from a project in which only fresh-water mosquitoes are concerned.

Sometimes mosquito abatement projects are organized without including all the territory necessary for really effective work, either because of inadequate preliminary studies or ignorance, or sometimes because of political interference. On the other hand, it is possible to include in a project areas which will not be benefited.

### District inspection

In the early stages of mosquito abatement, it is highly desirable to organize and carry out thorough house-to-house inspection of every dwelling and commercial or industrial building in the area to be controlled. In large cities this may require more than one season to complete.

The work of inspection must be organized properly for efficient and economical coverage and the personnel must be carefully selected. The inspectors must not only be intelligent and well trained on the technical side of their work, but they must be capable of meeting all types of people and educating them without offending them. We have used with good results college students specializing in either entomology or sanitary engineering. Such men are available during the summer months. The bulk of the work, however, must be carried on by the regular personnel, and it should therefore be planned in such a way that it can be taken up or laid aside temporarily according to the major requirements of drainage or oiling work.

In inspecting large tracts of marsh to locate the precise areas where there is breeding, it is always advisable to mark off the marsh into definite sections, which can be completed one at a time. It is a common experience that inspection of an extensive marsh area, say of 500 acres or more, will not be thorough unless systematized so that no portion is overlooked.

One way that is fairly satisfactory is to use stakes, six to eight feet long, preferably painted white or bright orange, as markers set along the edges of the marsh and about at the mid-point of the marsh, and dividing it into strips about 300 feet wide. An inspector can then go over each strip in turn, or several men can be worked at a time by assigning each man to a strip. The inspector can line himself up with the three stakes by eye, so that he knows when he has come to the edge of the strip. Breeding areas, when located, can be marked (either for a following oiling crew or for future examination) by setting up a plain unpainted stake in the center of the breeding area.

The method can be used successfully on extensive marshes which are not wooded or have very few trees. It is applicable especially to extensive salt marshes. It cannot be used on swamps with dense, tall grasses or tules or many trees.

### Inspections following complaints

The form in which a complaint or service request is made will often indicate the best method of inspection. Frequently the complainant will state that she (it is usually a woman who sends in the report) suspects a neighbor's premises as the breeding place, and doesn't want it known that she complained. Fear of unpleasantness in the neighborhood is the reason for this. In such cases it is advisable to begin the inspection a few houses distant (if in an urban area) from the complainant and ask at each house whether they have noticed any mosquitoes recently. If present, it will be possible within a short time to define the limits of the area in which mosquitoes have been noticed. The breeding place will be either near the center of the infested area, or if in a region where there is a fairly steadily prevailing breeze, near the windward edge of the area. The premises of the complainant will be examined during the inspection and the same inquiries made as were made of the other persons in the neighborhood.

While making inquiries as to mosquito prevalence, inspections of premises for breeding places can be carried on and also search for adults to determine the species.

Another form of complaint that may be received is that the complainant was badly bitten at a certain place the previous evening. In such cases also it is advisable to conduct the inspection as if it were being made as a routine matter rather than the follow-up of a complaint.

Routine inspections, either in urban districts or rural territory, should be made the basis for educational work. The occupant should be called on before the inspection is begun, the purpose of the visit explained, and the occupant asked to accompany the inspector about the place. When a breeding place is found, the larvae and pupae should be pointed out and the proper remedy explained and, if possible, applied on the spot.

Under some circumstances it may be necessary to make inspections at night, especially if daytime inspections fail to locate the source of breeding or fail to find adult mosquitoes. In that case the inspector has to use himself as a decoy for the mosquitoes and by judging from the frequency with which he is attacked, determine when he is nearest to the breeding place. Night inspections may be necessary in cases where it is especially difficult to locate the breeding place.

It is not necessary to resort to an elaborate system of recording the information obtained on routine, or on complaint, inspections. A well-trained and experienced inspector will usually find the breeding place, if any, within a few minutes. The occasional difficult case, however, may make necessary a careful analysis of all available information. In that case, the data for each premise may be recorded on cards, and a "spot" or "pin" map made use of. The proper relative weight should be given to matters of fact as determined by competent inspectors and to matters of opinion uttered by residents who have no technical knowledge of the subject.

The average person has little or no understanding of the life histories of the different species of mosquitoes and he sometimes has peculiar ideas as to their breeding places. People frequently make what may be termed the error of the obvious. If there is a creek or a reservoir in their vicinity, they will attribute all their mosquitoes to such places, which on inspection may be found to be entirely free from mosquito breeding. As a rule, the opinions expressed by the average citizen are of small value and should be tested and confirmed or rejected on the basis of facts. Even the statement that they are bothered and bitten by mosquitoes is at times erroneous or even willfully wrong, though the latter is rare. In some cases people who see small swarms of gnats or midges will report them as mosquitoes. Occasionally persons will report annoyance from mosquitoes when there are none present, for the purpose of obtaining, if possible, the correction of some unsanitary condition in the vicinity which has no relation to mosquito breeding.

In some cases people may grossly exaggerate the number of mosquitoes present, with the idea probably of getting more or quicker attention from the official in charge of mosquito abatement. Some people are supersensitive and will magnify one mosquito into a whole fleet of imaginary gallinippers. Also an occasional practical joker will be encountered who will make a complaint merely because the whole idea seems humorous to him.

On the other hand, people will frequently be found who will either minimize the presence of mosquitoes, even of a severe infestation, or deny their presence entirely. These are of two types, as a rule: the insensitive person who does not notice the presence of insects, or the person who conceals the matter from ignorance or from fear of prosecution or from fear of the animosity of neighbors. In all cases the inspector should endeavor to develop the facts from his own investigation and observation.

While it is no doubt true that a natural detective sense is more thoroughly developed in some men than in others, and that they become more proficient than others in locating mosquito breeding places, nevertheless excellent and effective work can be done by anyone who will take the pains to do a *thorough* and complete job of inspection. Many cases have come to our attention where good results were not secured simply because of lack of thoroughness. Too frequently the obvious thing is taken as the breeding place when it is really only a minor point. For example, on a complaint, a rain barrel and a lily pond may be found breeding mosquitoes and accepted as the cause of the complaint, when actually a concealed cesspool may be the source of the greatest number of mosquitoes in the vicinity. Two examples which occurred in Oakland, California, may be cited.

In the first case, complaints were received from an apartment house near the center of the city that mosquitoes were very bad at night. The region was inspected and two lily ponds, a few tin cans, and a sewer catch basin were found breeding. The people were told that the mosquitoes had been abated and that the trouble would probably stop. In a few days, however, more complaints were received and another inspection made, but nothing new was located. From then on for a week or more the complaints became frequent and bitter, and much criticism of the incompetence of the inspectors was voiced. Other inspectors were brought in who went over the area carefully and independently but could find nothing new of sufficient importance to produce the really great infestation. It was then necessary for the engineer of the district to review carefully all the facts and evidence on the ground and, by process of logical deduction from the number of adults found and the direction of the prevailing winds, to narrow the locality of the breeding place down to a radius of perhaps fifty feet. Within that radius it was evident that there must be a considerable surface of concealed water, which was finally discovered in a room under a building walled in and floored over so as to be completely concealed, although leaving ample cracks and crevices for the entrance and exit of mosquitoes. The water came from a natural spring. The water surface in this room was twenty by thirty feet in surface dimensions, and about four feet deep. *Culex pipiens* were breeding in vast numbers. The water was immediately oiled and the infestation cleared up promptly.

In the other case, it required about two months of inspections and constant reinspections to clear up an infestation in a small residential area, during which period the residents did not regard the ability of the abatement forces very highly. A series of abandoned wells and some wet basements were ultimately found to be breeding *Culex pipiens*. More thorough inspection in the beginning would have produced results more quickly, but the inspectors as well as the residents were deceived by some obvious breeding places.

We also know of a number of cases where infestations of *Culex pipiens molestus* have persisted in concealed breeding places for several years in spite of intensive searches for the source. In one case it was seven years before a forgotten underground cesspool was finally found.

Probably the most difficult breeding places to locate are those resulting from a broken or clogged sewer or drain under an old building, particularly if the lower floor of the building is near ground level and there is two feet or less clearance between the ground surface and the bottom of the floor joists. A number of such cases have come to our attention; sometimes it has taken several weeks of intensive search to locate the breeding place. Usually such breeding places can be located only by tearing up some of the floor boards.

It is usual practice, when a mosquito breeding place is found, to show it to the occupant of the premises and inform him (or her) how to prevent future breeding. Often this is all that is required to prevent a repetition. But in a great many cases, either through carelessness, indifference, or ignorance, breeding will reoccur.

### Follow-up inspections

Successful control work therefore demands that occasional follow-up inspections be made to prevent a recurrence of the trouble. This is the weakest point in most mosquito abatement projects as funds are frequently inadequate for thorough reinspections. Complaints and the location of new or not heretofore discovered breeding places take most of the energies of the available personnel, so that reinspection tends to be neglected.

The proper handling of reinspections requires some form of office system which will make it possible to systemize the work so that a considerable number of places can be covered in minimum time and with the least travel. For this purpose, cities can be divided into sections. The premises to be inspected within such sections can be spotted on a map and the inspector then routed for the least amount of travel. The information for the inspector may be placed either on cards, arranged in the order to be examined, or on a route sheet.

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# VII

## ABATEMENT METHODS: GENERAL PRINCIPLES

In the selection and application of abatement methods, a few principles and practical considerations deserve special attention.

### Effectiveness and economy

Principles basic to all abatement work are: 1) that mosquito production shall be eliminated as completely as is possible under the existing conditions and 2) that primary methods of abatement such as drainage or naturalistic control shall be used to the fullest extent possible, in preference to secondary measures such as oiling. These are the ideals which should be aimed at. Situations will be encountered in which they cannot be attained practically or within reasonable cost limits, and under such circumstances some form of compromise must be resorted to; but the fundamental aim of effective control of mosquito production and emphasis on primary abatement measures should never be lost sight of.

It is to be noted particularly that *the elimination of mosquito production* is the fundamental requisite of mosquito abatement. We cannot emphasize this too strongly, and even at the risk of repetition we will reiterate and re-emphasize it throughout this book. There are certain situations of minor importance where measures for the destruction of adult mosquitoes are useful in the anti-mosquito campaign, but they are limited usually to tropical situations and military campaigns. Prevention of mosquito breeding, on the other hand, or the destruction of the larval forms of the mosquito if it is not practicable or possible to eliminate mosquito breeding places, is of major importance in the abatement campaign.

If, as is usually the case, more than one method of abatement is effectively applicable, the method of choice will be that which is most economical. Assume, for instance, two methods, one of which can be expected to effect ninety-five per cent reduction of mosquito breeding at an annual charge of four dollars per acre of breeding area, and another which can be expected to effect ninety per cent reduction at a yearly cost of two and a half dollars per acre. If the five per

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cent difference in mosquito output will not cause an appreciable difference in either disease transmission or personal comfort, the second method should be chosen. But remember always that the mosquitoes you fail to destroy cause the public to complain.

In general, it may be stated as axiomatic that in urban areas in the temperate zone complete abatement of *all* species of mosquitoes should be the aim. The people who pay taxes for mosquito abatement expect results and excuses do not allay the misery of dengue or the irritation caused by mosquito bites and disturbed sleep. Complete eradication is probably impossible even under urban conditions because the average person's carelessness creates new breeding places faster than any reasonable abatement force can locate them.

If disease prevention is the primary purpose, as it must be in areas infested by disease-carrying mosquitoes, then the abatement measures must be directed first against those species which are disease vectors and the initial aim should be to reduce their numbers below the point where they can be effective in transmitting the disease. For any mosquito-transmitted disease in a particular region there is an approximate number of vector mosquitoes per capita above which the disease will be endemic and below which it will decline to merely occasional cases. Ross[1] indicated this years ago and we believe that the basis of his argument is still valid. However, *Anopheles* density of itself is not the sole criterion, for as Williams[2] and others have pointed out, the living habits of the people in a region will modify the *Anopheles* density per capita which is necessary to maintain an endemic malaria. For example, in a region where all houses are well screened it is almost certain that a much greater number of vector *Anopheles* per capita will be necessary to maintain an endemic malaria than in a region of unscreened homes. In general, the same principle will apply to other mosquito-transmitted diseases. Depending upon living conditions and climate, there will be in any region some limiting number of vectors per capita below which yellow fever or dengue cannot become epidemic and filariasis cannot maintain itself endemically.

While there may be room for considerable speculation as to the approximate number of vectors per capita necessary to maintain an endemic mosquito-transmitted disease, there can be little doubt that it must be an appreciable number. For malaria, Ross suggested—on a calculation of the probability of one mosquito biting an infective malaria case, living two weeks or more thereafter, and then biting a susceptible person—that at least forty *Anopheles* females per capita would be necessary to maintain an endemic malaria. Others who have studied the problem, while not giving specific indices, are agreed that many *Anopheles* per capita are required.

Ross's idea of a vector-human numerical relationship below which endemic malaria cannot be maintained has had partial confirmation recently in the studies of Russell and Rao[3] on the prevalence of malaria and *Anopheles culicifacies* in adjacent areas in the Tanjore district, Madras, India. Since the introduction of a new irrigation system in 1933, malaria has been endemic in the newly irrigated area, the spleen index rising to an average of about 40 per cent, with rates of 80 per cent in some villages.

The old Tanjore delta near by has been irrigated for centuries, and *Anopheles culicifacies* is present, yet surveys in this area yielded no positive blood smears and the spleen rate was normal, indicating little or no malaria, as contrasted with the adjacent newly irrigated area. By making standardized per-man-hour collections of *Anopheles culicifacies* in dwellings in both areas, it was found that the density of the vector was three to four times greater in the newly irrigated area, which is highly malarious, than in the old irrigated delta, where malaria is practically absent.

As other conditions are substantially the same in the two areas, it appears to be very probable that the density of the vector, in relation to the number of humans, is the critical factor in maintaining an endemic malaria. Above that critical density malaria will become and remain endemic, and with a high density may become epidemic; below that critical density malaria will cease to be endemic and will ultimately die out, except possibly for sporadic cases.

What that critical density, or ratio of vectors to humans, is will probably not be a constant numerical ratio, but will vary according to climate, housing, nutrition, medical care, and other factors characteristic of the region and its people.

It appears to be obvious that this general reasoning applies equally well to other mosquito-transmitted diseases such as yellow fever, dengue, and filariasis. It is only necessary that the number of vectors be greatly reduced over a reasonably long period of time, even though the vector species is not extirpated, to cause such diseases to disappear in the controlled area.

Furthermore, it explains why a "continuity of modest effort" may succeed in the control of an insect-transmitted disease, when one or two seasons of intensive work, followed by neglect, may fail to accomplish permanent results.

After the vector species has been reduced below that mosquito-per-person ratio at which a mosquito-transmitted disease can be effectively maintained, there still remains the question of comfort and how much shall be paid to attain it. That can be solved only for each particular area by a study of local conditions. The price that will be paid for disease prevention is one thing; what will be paid for comfort is another. Too frequently, we believe, the standards of comfort are not high.

Among native peoples in the tropics, the discomfort caused by mosquitoes and other insect pests is accepted as a matter of too little consequence to warrant the effort required to eliminate pest mosquitoes. On the other hand, a community in the process of real estate development will willingly pay a considerable sum for relief from pest mosquitoes for the reason that mosquito prevalence plays havoc with sales of real estate.

### Adapting abatement measures to mosquito species and breeding habits

The abatement method must be suited to the species of mosquitoes involved. Drainage is not applicable, as a rule, to the control of *Culex pipiens* or *Aedes aegypti*. House-to-house inspections for local breeding places are of no use in combating *Aedes sollicitans* or *Aedes squamiger*. These statements are obvious to a trained entomologist, but are not evident to persons without at least an elementary entomological training.

It may even be necessary to distinguish between sub-species of mosquitoes and, when funds are limited, to adjust the abatement measures to a selective control of the sub-species which is a disease vector and relatively to neglect control of the sub-species which does not transmit disease effectively. This situation occurs in many areas where *Anopheles maculipennis* is the vector of malaria.

Hackett, Martini, and Missiroli,[4] and Hackett[5, 6] have shown that in Europe there are several sub-species or varieties of *Anopheles maculipennis* that are practically distinguishable only by characteristics seen in the eggs. It is possible that we are presented here with the beginning of an evolutionary differentiation in species which has so far progressed in anatomical features only in the egg stage but which in time may progress further to distinct anatomical differences in the larvae and adults. The differentiation has also progressed physiologically in the adults to the point where some of the sub-species have apparently acquired habits or food preferences which interfere with their ability to act as vectors of malaria. Possibly this may be due to the development of zoophilism (that is, the preference for animal blood rather than human blood). The whole subject has tremendously interesting speculative possibilities and writings on the subject may be read with profit. From a practical standpoint differentiation serves to explain the relative absence of malaria in some regions of comparative abundance of *Anopheles maculipennis,* the unusual seasonal distribution of malaria in other regions, and the comparatively high incidence of malaria in some regions where *Anopheles maculipennis* is not abundant.

From the standpoint of control of mosquito breeding *per se,* the racial variation of *Anopheles maculipennis* is usually of slight significance to the man in charge of abatement procedures. He seldom has time to collect larvae, hatch them out, allow them to breed, and then examine the eggs. These necessary preliminaries should be carried out by a special technical staff to determine if possible the areas producing vector and non-vector varieties. The greatest efforts would then be concentrated in the areas producing vector varieties. However as mosquito abatement measures should consider comfort as well as disease prevention, the abatement of non-vector varieties should be carried on concurrently unless restricted funds prevent.

This subject is a phase of species sanitation, which is discussed more fully in CHAPTER XVII.

Particular attention must be paid to the breeding seasons of the mosquitoes prevalent in the region. Lack of timeliness in the application of abatement measures is frequently the cause of failure to achieve successful mosquito abatement. Several instances have occurred where considerable expense for mosquito abatement has been incurred after a single-brooded species emerged, resulting in a complete waste of money and no abatement whatever.

A common remark made to mosquito abatement officials by well-meaning but uninformed citizens along about July of each year is "I suppose you are getting very busy now killing mosquitoes." Actually, if the men had not been busy during the winter months and intensively busy during the spring months, the mosquitoes would be so far ahead of them that they could never catch up with the pests until the next winter. For example, in mid-coastal California *Aedes squamiger* larvae begin to appear in rain water on the salt marshes during January. From then until about the end of February every effort is made to drain away as much of the larvae-containing water as possible and to supplement by pumping in cases where the grades are very flat. The first ten days in March are devoted to oiling to kill any larvae remaining. As the annual brood of *Aedes squamiger* emerges usually about March tenth, it is obvious that control of this species in the San Francisco Bay region would be entirely ineffective unless begun in January and completed prior to March tenth.

Other examples of single-brooded mosquitoes are *Aedes cinereus*, *A. stimulans*, *A. excrucians*, *A. communis*, and *A. flavescens*. Usually these species are inhabitants of areas having short breeding seasons because of latitude (for example, Alaska and northern Canada), or because of high altitude (for example, *Aedes hexodontus*), though some species (for example, *Aedes cinereus*) are apparently single brooded even under temperate conditions. *Aedes vexans* may have only a single brood in the spring in the central valleys of California on account of the absence of summer rainfall, but in New York State it usually has two broods, spring and autumn. In New Jersey and in Illinois, if the rainfall occurs at the proper times, this species apparently may produce more than two broods per season.

Some species in certain localities will breed throughout the year. *Culex pipiens*, for example, may breed through the winter in protected places such as underground street vaults of the telephone companies, in all regions where continuous subfreezing weather does not occur. In western United States wherever severe freezing does not occur, *Culex tarsalis* may breed throughout the winter. In California it breeds throughout the year, favoring especially the foul water in dairy drains. Under most subtropical and tropical conditions mosquito breeding is continuous or practically continuous.

### Practical considerations concerning equipment and labor

In the application of abatement methods, the practical question arises whether particular items of equipment should be purchased or rented. The answer depends largely on local conditions. In general, transportation equipment such as light trucks for general duty and a minimum of excavating tools, hand sprayers, and the like may be purchased at the start and added to as required. Tank trucks, power sprayers, and excavators had best be rented in most cases, or the work they are to do performed by contract. In any case, the following cautions should be emphasized:

1. When in doubt, don't buy equipment—rent it.
2. More errors are made in buying expensive equipment, for which there is not enough use to justify its purchase, than almost any other error in judgment in this or similar work.
3. Even if it proves an error to rent rather than purchase equipment, an initial error in this regard is easily corrected without great loss.
4. Even if it appears at the start of work that some equipment purchases may be justified, conditions may change and little use be had later for such equipment—be conservative and cautious.

In CHAPTER XII, page 254, a specific instance is presented to indicate a method of determining whether equipment should be purchased.

Another important practical question is whether particular abatement operations should be performed with laborers employed by the abatement agency, or performed by contract. In general it will usually work out best to carry through the larger jobs by contract, particularly those which require heavy equipment such as floating dredges or caterpillar-mounted drag-lines or clamshell excavators; and to do the smaller jobs, particularly those which can be done by hand, with labor employed by the mosquito abatement agency.

On some large jobs it may prove economical and satisfactory to hire the heavy equipment from an agency which rents drag-lines, power shovels, tractors, and the like, and to operate them with abatement agency employees. But as a rule a contractor is better equipped to handle large jobs than is the mosquito abatement agency. The contractor has the organization and personnel experienced in that class of work and can usually do the job cheaper than, and as well as, the district could and still earn a profit for himself.

Some fairly large jobs can be done by hand labor, but the cost is always prohibitive as compared with machine work; and excavating machinery can do the work much more rapidly than hand labor. A considerable amount of mosquito abatement drainage was done during the winter of 1933–34 in the United States by the Civil Works Administration relief employment program,[7] and was continued in succeeding years under federal work-relief agencies. These projects were usually hand labor jobs, sometimes supplemented by machines, but most of them could have been done much more cheaply and quickly by machinery under contract.

Some types of work can only be accomplished by floating dredges. Such jobs can best be done by contract either at a flat price or at a price per cubic yard of excavation or of embankment. Floating equipment can also be contracted for on a daily or hourly basis, in which case it is not necessary to measure the quantity of excavation or embankment. Contracts of this type are best made on the basis of a fixed sum per hour of actual working time plus a flat sum for moving the equipment to and from the job and with a penalty clause for exceeding the time set for completion. In some jurisdictions a penalty for excess time may not be imposed without offering a corresponding bonus for completion prior to a certain date.

The foregoing statements are valid during normal times when adequate labor is available at reasonable rates. The effects of the present war may invalidate them, at least in part, and make it advisable to use increased quantities of mechanized equipment, regardless of apparent economics, if the work is to be done at all under labor shortages or excessively high wage rates.

### Wild-life conservation and mosquito abatement

There is no necessary conflict between mosquito abatement and wild-life conservation, and the trained biologists of governmental conservation agencies have had no difficulty in obtaining mutually satisfactory programs with those mosquito abatement agencies which are directed by men with adequate biological training, especially those with a thorough understanding of ecology.

It must be recognized that both the mosquito abatement movement and the conservation movement have been afflicted with persons, no doubt sincere, who have had too scant a knowledge of their respective fields. Some mosquito abatement work through gross ignorance has distinctly and unnecessarily damaged large areas which were of value in the preservation of marsh and migratory birds or of animals such as muskrats. Far greater damage has been done by unnecessary and even foolish agricultural schemes, by the expansion of industry and of municipalities, and by the ruin of littoral marshes through massive pollution by sewage and industrial wastes.

On the other hand, skilled mosquito abatement work which utilizes to the maximum natural or biological control procedures not only does not damage areas available to water fowl, but in some cases has actually increased the availability of such areas. J. Lyell Clarke[8] in Illinois has been successful in this work and many others could be commended, for example, S. L. Crosthwait in Maryland, M. H. Price in Rhode Island, and F. W. Rush in California.

The method of controlled reflooding, explained in CHAPTER IX, should be given far greater practical application by mosquito abatement agencies and greater advocacy and support by conservation agencies. Impounding of water on marshes at a constant level, with water circulation and fish control, is also a method acceptable to conservationists, as is the method of open marsh ditching[9] recommended in CHAPTER IX.

In planning and conducting mosquito abatement work under conditions which may affect migratory birds or aquatic animals, the mosquito abatement agencies should consult with the technical personnel of the United States Bureau of Biological Survey and the state fish and game commission, or similar bodies in other countries. There need be no difficulty in arranging mutually satisfactory programs by means of conferences between the technical personnel of the conservation and abatement groups.

All types of mosquito abatement projects do not concern the conservationists. Some have to do only with mosquito breeding in urban areas in which wild-life conservation is not at all involved, and others with agricultural areas in which wild-life conservation is only slightly involved or in which the effects of mosquito abatement are minor as compared with the effects of agricultural reclamation. But there are mosquito abatement projects, especially marsh projects in the vicinity of large centers of population, where unnecessary damage to wild life can be caused by bungling and unskilled mosquito abatement methods; or marsh areas remote from human habitations where mosquito abatement may be entirely unnecessary and indefensible on economic as well as conservation grounds. In such cases the conservationists have a legitimate interest and certainly in the latter cases a paramount interest.

Mosquito abatement agencies which are conducting their work on a sound technical basis with due regard to conservation requirements have a right to protection from unwarranted attacks by some elements in the conservation movement. Conferences and cooperation with scientific conservation personnel will be of real assistance, but at times direct publicity may be necessary to combat malicious or distorted attacks. It is advisable to try to forestall criticism by letting it be known that wild-life conservation is being given adequate attention, but this should preferably be done as an incidental matter in connection with news reports of work accomplished or planned. It is usually inadvisable to press the matter as a main issue unless the abatement agency is under attack; to do so might start an argument developing more heat than light.

### Summary of general principles

The general principles in the selection and application of abatement methods may be summarized as follows:

1. Adopt those measures or combination of measures which, with due regard to economy of operation, will be effective in eliminating mosquito production as completely as possible; place emphasis on primary methods of abatement such as drainage, in preference to secondary methods such as oiling;
2. Adapt the abatement measures to the species of mosquitoes and to their particular breeding habits in the region;
3. Adopt naturalistic and biological methods of control to the greatest extent possible;
4. Concentrate the principal abatement efforts on the vector species of mosquitoes, if mosquito-transmitted disease prevails in the region;
5. But even when primary attention is given to disease prevention, do not neglect the elimination of pest mosquitoes, unless local conditions clearly indicate otherwise;

6. Confer with the technical personnel of conservation agencies and secure their cooperation in planning methods of control which will conserve wild life to the greatest extent compatible with effective mosquito abatement;

7. Start larvicidal work early in the spring, with the first appearance of larvae; try to be ahead of the mosquitoes;

8. At the end of the breeding season, intensify efforts in order to reduce the last brood to a minimum and to leave the smallest possible number of over-wintering adults or eggs to start next year's brood;

9. Use the winter months for maintenance work on drainage systems, for construction of new drains and other permanent structures, for overhauling equipment and getting it in shape for next season's campaign, and for planning the following year's work;

10. Exercise restraint in the purchase of expensive equipment;

11. Usually do large construction jobs by contract;

12. Develop an effective staff organization which will know its species of mosquitoes, its territory, and its people; keep key men continuously employed throughout the year and secure in their jobs, if necessary assigning foremen and inspectors to laborers' duties during the winter.

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## VIII

# DRAINAGE AND RECLAMATION OF FRESH-WATER MARSHES

ANY OPEN water which is not subject to active movement (circulation or surface agitation) or which on receding leaves residual pools may provide breeding places for mosquitoes. The elimination of widespread mosquito breeding water by drainage is in most cases the most effective anti-mosquito measure since it robs the mosquito of its breeding place and thus affords the best possibility of complete and relatively permanent abatement.

Applications of oils and larvicides are essentially substitute or auxiliary measures of temporary or seasonal value to be employed when drainage is not practical or not completely effected. The possibilities of drainage should therefore be thoroughly explored in each instance and constantly kept in mind in conducting an abatement service.

Fresh-water breeding areas (excluding from present consideration water in artificial containers) present drainage problems essentially distinct from those of salt marshes which are discussed in the following chapter. Various types of fresh-water areas, such as those in deltas, lake regions, irrigation districts, valleys, and mountains, also show fairly distinctive problems. The principal factors of differentiation which affect the type and cost of abatement measures are: 1) extent of the water area; 2) slope or grade available for removal of surface water, ranging from no grade or negative grade in delta regions to steep declivities in mountain regions; 3) soil conditions varying from fine silts to hard rock; and 4) meteorological conditions, such as climate, rainfall, and temperature. The problems of drainage thus vary to a great extent with geographic regions and geological structures.

### RIVER BOTTOM, DELTA, AND OVERFLOW LANDS

River bottom, delta, and overflow lands may be grouped under two heads:

1. Lands which lie above the normal water level but below the flood level;
2. Lands which are practically at the normal water level.

The first type requires the construction of drain ditches properly located and of sufficient size to cause a rapid and complete run-off of flood waters. Usually natural drainage channels will be available, which require only clearing and grading or possibly straightening and enlargement and which will provide economical main drainage lines. Into these natural drainage courses the required drain ditches will then be directed.

Two difficulties, however, may be encountered: 1) flood waters containing considerable quantities of silt may fill in the drainage channels; 2) large floods may by scouring action destroy some or all of the drains. In either case the maintenance costs for drain ditches would be excessive, and it would probably be an economy to construct dykes or levees which will either prevent scouring by flood water or will act as holding basins during and after floods so as to cause silt deposition and the ultimate building up of the ground level to the elevation of the flood plane.

Some rivers, such as the Mississippi and the Sacramento, actually travel in a section of the valley floor which has been elevated above the general valley level by deposition of silt during floods. As a result there are troughs roughly paralleling the main stream on one or both sides of the river and at varying distances from it. The land slopes laterally from the river down to these troughs (called sloughs or bayous). Their drainage may be an engineering task of considerable magnitude. Mosquito control in such regions generally must depend on fish, proper attention being given to the opening up of small breeding areas to which the fish can have free access. Extensive planting of *Gambusia affinis* should be tried, but the practical limitations of these fish as stated in CHAPTER XIII should be borne in mind; oil or larvicide may also be required on an extensive scale. Probably access to such regions will be best obtained by small motor launches of light draft.

The most economical and effective remedy can only be applied after the flood characteristics of the river and the silt content of its flood waters have been ascertained. It may be advisable to use oiling methods for a few years until the area has been under observation long enough to determine the best and most economical permanent abatement procedure.

On deltas and bottom lands which are practically at the normal low-water level and which are not subject to tidal influences, permanent abatement can usually be effected only by reclamation of the territory by dykes and pumping. This involves considerable expense. Frequently the capital outlay and the pumping costs cannot be justified for mosquito abatement alone. The financial justification of such projects then must lie in the agricultural value of the reclaimed land. As river bottoms are generally exceptionally fertile, the increase in value of the reclaimed land will almost invariably far offset the cost of reclamation.

As a rule the cost of reclamation should be borne by the owners of the property who are benefited; but it would appear to be reasonable for a public mosquito abatement agency to contribute a part of the cost. The amount contributed will vary with circumstances, but should not exceed the difference in annual expense of mosquito abatement measures on the property before and after reclamation capitalized at the normal rate of interest.

Reclaimed bottom lands require a system of drainage ditches leading to the pumping station. Usually a main drain is constructed around the property, interior to the protecting dykes. This drain may be simply the borrow pit from which the material was obtained for building the dyke. Such a pit must be made continuous throughout and excavated with a uniform bottom grade sloping to the pumps. Variations in yardage requirements for the dyke should be obtained by varying the width but not the depth of the borrow pit. This drain or pit should intercept and conduct to the pumps any seepage water from the adjacent wet lands. Other main drains running through the property are also required, primarily for agricultural drainage. Into such a system of main drains a series of smaller laterals should be constructed as required for the prevention of the accumulation of any mosquito breeding water.

Such reclamation projects, especially if of any magnitude, should be carried out under skilled engineering supervision and should be investigated carefully before being undertaken. One of the important points to be considered is the amount of soil shrinkage which will result. In peat and muck soils the shrinkage may be ten or more feet over a period of several years,[1] and this drop in surface elevation must be allowed for in the design of the dykes, the depth of the drains, and the selection of the type of pumping equipment.

Reclamation work of this type is usually performed with floating excavating machinery using either drag-line or clamshell buckets. Land operated machinery usually cannot be used owing to soft and unstable ground. The engineering details are discussed in various texts, to which reference should be made if such a project is under consideration.[2]

Delta lands which are subject to tidal fluctuations of several feet can sometimes be reclaimed with dykes and automatic drainage gates provided there is no danger of subsidence or shrinkage of the soil after drainage. This type of drainage is discussed in greater detail in the next chapter, pages 174–183.

Drain channels in river bottom land should be constructed with careful consideration of the nature of the soil, so as to keep the cost of maintenance at a minimum. Loose and sandy soils will require flatter side slopes than clay soils to prevent stoppages due to bank caving. The bottom grades of the ditches must also be kept within such limits as to prevent cutting by too high velocities of drain water in the ditches. Usually this is not a problem in flat regions.

The cross-sectional dimensions of the drains should bear a proper relation to the area drained so as to avoid channel velocities so high as to cause scour. *Gambusia affinis* should be planted freely in the main drains. Pump suctions should be screened to prevent the fish from being pumped out.

### Lakes and lake regions

Lakes in themselves are not necessarily mosquito breeders for the reason that there is sufficient surface wavelet movement to discourage ovipositing and to prevent successful emergence of the adult mosquito from the pupal stage. Furthermore lakes usually have sufficient fish life to keep the water free from mosquito larvae. Many lakes, however, have marginal shallow areas and swampy ground, particularly at the upper or inlet end, which may be prolific breeders. Smaller lakes also may be subject to variations in elevation of the water surface of several feet, in which case as the water level recedes marginal pools may be left which are ideally adapted to mosquito breeding. Such cases usually can be effectively and cheaply drained by small ditches arranged according to topography in such a way as to prevent the occurrence of isolated pools or of swampy areas. In some cases filling in of low areas will prove the best method.

In lake regions of former glacial activity the cost of drainage may be relatively great owing to the presence of boulders and coarse gravels. Special excavation methods, including the use of dynamite for blasting boulders, may be required.

Very shallow margins of lakes or reservoirs, especially if of any considerable width, may produce growths of vegetation or algae which may permit mosquito breeding. If these margins cannot be either filled in or deepened sufficiently, oiling will probably have to be depended upon. Usually the effectiveness of the oil can be increased by giving these shallow margins a treatment of copper sulphate to kill off the algae growths.

### Valley floors and plains

Although the general impression of extensive valleys and plains is that of flatness, a detailed examination shows that an appreciable slope of the land surface exists. Natural streams and drainage ways are to be found throughout and the ground surface slopes laterally toward these drain ways. In addition there is a general slope of the entire area, such as the easterly down-grade of the Kansas-Nebraska plains and the southerly down-grade of the Sacramento Valley.

Mosquito breeding swamps occur naturally on such plains or valleys due to local flattening of the grades, in the vicinity of natural springs, and at or near the point where streams from adjacent hills debouch upon the valley.

Where there is a local flattening of grade, the drainage problem is simple in conception although in some cases considerable excavation may be required. A main drain will have to be constructed through the flat section with adequate grade to carry off the surface water; laterals should also be constructed according to the requirement of topography and soil condition (see Figure 15).

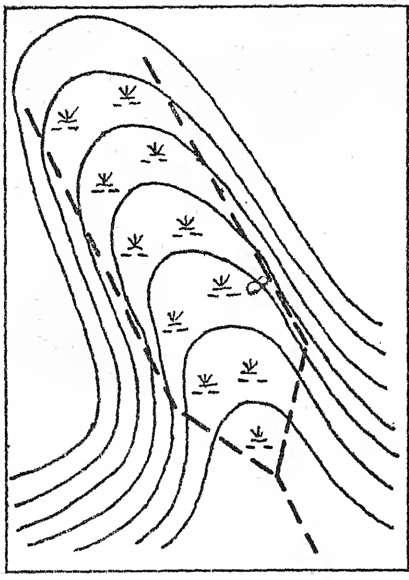


Figure 14. Circumferential cut-off drains to intercept seepage water

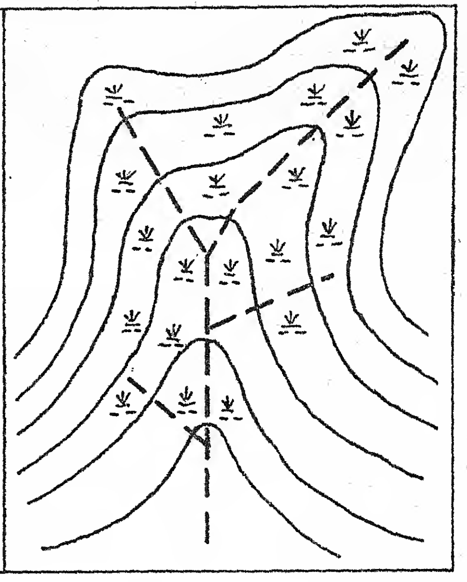


Figure 15. Main drain and laterals for simple swamp area

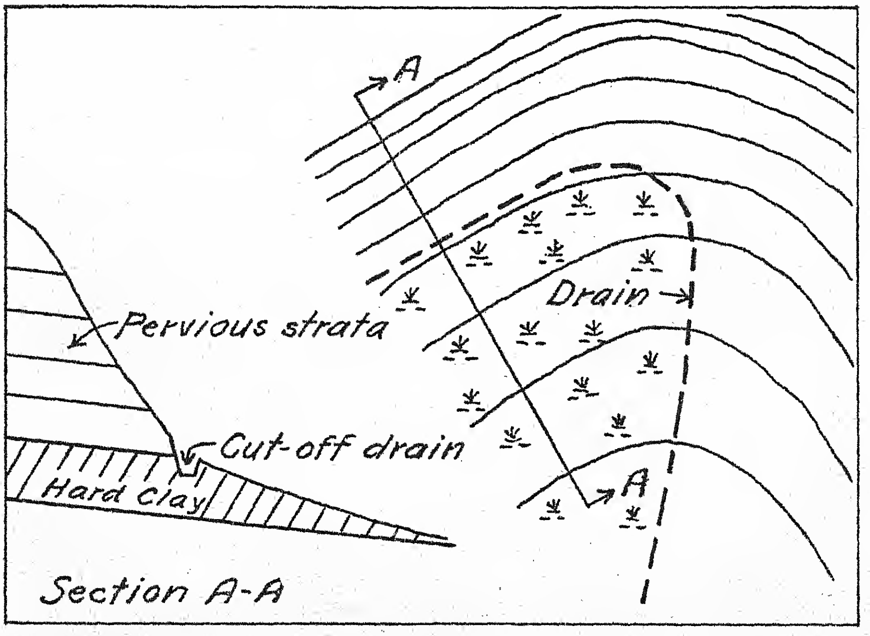



Figure 16. Drainage of a swamp caused by a side-hill seepage on a lower impervious stratum

If the swamp is the result of a seepage (see Figure 14), a central main drain with laterals is not usually effective. In this case a system of deep circumferential cut-off drains is required to intercept the seepage water and conduct it around the wet area. The drains must be deep enough to catch the seepage water and the grade steep enough to carry it off rapidly and so to prevent seepage through the down-hill side of the drain. In some cases considerable ingenuity will have to be exercised to get thorough drainage. The important thing is to locate the outcrop of comparatively impervious material underlying the water-bearing stratum (see Figure 16) and to construct the drain across the face of it so as to intercept the seepage.[3]

Where streams debouch from hills on to a relatively flat plain or valley there is sometimes a tendency for the water, particularly from heavy rains or the spring run-off, to spread out over considerable area and to leave temporary pools which may breed mosquitoes. Usually these temporary pools can be more economically controlled by oiling than by ditching. In some cases, however, the spreading or overflow may be sufficiently frequent to cause marshy areas, in which case ditching will be most satisfactory. The drains should lead back into the stream at a lower level and will usually require considerable maintenance.

The Kern River at Bakersfield, California, is an example of a type of stream which makes mosquito abatement extremely difficult. This river debouches on to the flat valley floor after maintaining a rapid flow through high mountains and the foothills, and floods severely in years of above-normal precipitation. A flood-way is provided by means of lateral protective dykes, but maintenance of drains in the flood-way is practically impossible and as a result, when the spring floods recede, vast numbers of *Aedes vexans* breed in pot-holes and lagoons. A dense growth of brush also helps to make any form of control work very difficult.

### Rolling and hilly uplands

These regions have adequate grade for the carrying off of surface waters and in general mosquito breeding areas are likely to be found only where there is some artificial obstruction to drainage.

Railroad or highway embankments with improperly placed culverts are typical obstructions. After long and sad experience the writers are convinced that it is only by accident that either a railroad engineer or a highway engineer ever places a culvert properly. Usually it is set too high so that a pool or swampy area forms on the upper side of the embankment; occasionally it is set too low so that water remains in the culvert itself. Highway engineers have a slightly better batting average in this respect than the locating engineers for railroads, but there are plenty of illustrations of improperly placed highway culverts.

Dr. Carter of the United States Public Health Service is reported to have said that for every dollar of road construction performed in the southern United States twenty-five to fifty cents of impairment of the public health had been caused.

The bottom of the culvert should conform closely to the general ground surface gradient at the low point. To determine this, a profile should be taken along the bottom of the drainage way or depression for at least fifty feet, preferably one hundred feet, beyond the toes of the future embankment and the culvert elevation and grade properly fitted to this profile (see Figures 17 and 18).

Where existing culverts are improperly placed, officials of the railroad or the highway department should be interviewed, the situation explained to them, and a request made that the culvert be replaced at the proper point and to the proper elevation and grade. If the request is made in the interest of the public, the railroads will almost invariably, in our experience, make the necessary changes and do so in a very commendable spirit of cooperation. The highway departments, on the other hand, are somewhat different. If the head of the mosquito abatement work has established friendly relations with the heads of the highway or road department, they will usually be willing to make the change, but they are frequently handicapped either by lack of specific funds for the purpose or by lack of specific authority or by various forms of governmental red tape. If friendly relations have not been established, it is very often the case that such requests will be received with less than no enthusiasm. In either case considerable maneuvering and pulling of political strings may be required to get results.

### High mountain districts

Most persons who have visited the high mountains in summer, especially the Sierra Nevadas and the Cascades in North America, will remember the vicious and persistent attacks of swarms of mosquitoes. These are various species of *Aedes* hatched in melting snow water from over-wintering eggs. The numbers under some conditions are astonishing.

Over large parts of these mountainous areas mosquito abatement will prove so difficult and expensive as to be entirely impracticable. In other regions substantial relief may be obtained at reasonable expense, but complete freedom appears to be impossible. Almost always a summer camp in high mountain areas can be given reasonably good protection by intensive and *timely* control measures applied to an area within roughly a half mile radius of the camp.

Control of the mountain species of *Aedes* depends largely on oiling and larviciding. An oil of high spreading coefficient and of high toxicity is necessary because of the low water temperature. However, it will be found that a number of breeding areas can be either eliminated or greatly reduced in extent by drainage. This is usually the case on the mountain meadows where the rock is overlaid with some depth of soil. But where the bed rock is at or very close to the surface, so that drilling and blasting are required to put in a ditch, it is probable that the capitalized cost of oiling will be considerably less than the cost of ditching.

S. B. Freeborn and others have found by practical experience that the use of oil at the proper time is a definite deterrent to the deposition of eggs by mountain *Aedes* mosquitoes. When all water available for mosquito breeding purposes in a particular mountain area is sprayed with a suitable oil, whether mosquito larvae are then present or not, little or no mosquito breeding will be found in such pools the following year. On the other hand, if only the pools in which breeding occurs are oiled, then in the next year breeding will occur in the unoiled pools but not to any great extent in the pools oiled in the preceding year. Of course it is assumed that the oiling is thoroughly done, the littoral wet ground being sprayed as well as the water surface. If there are two or more species involved whose breeding periods do not overlap, it is assumed that oil will again be applied to destroy and deter the later breeding species.

This procedure may not be effective for all species of boreal *Aedes*, but it does suggest that the protection of resort areas in high moun-

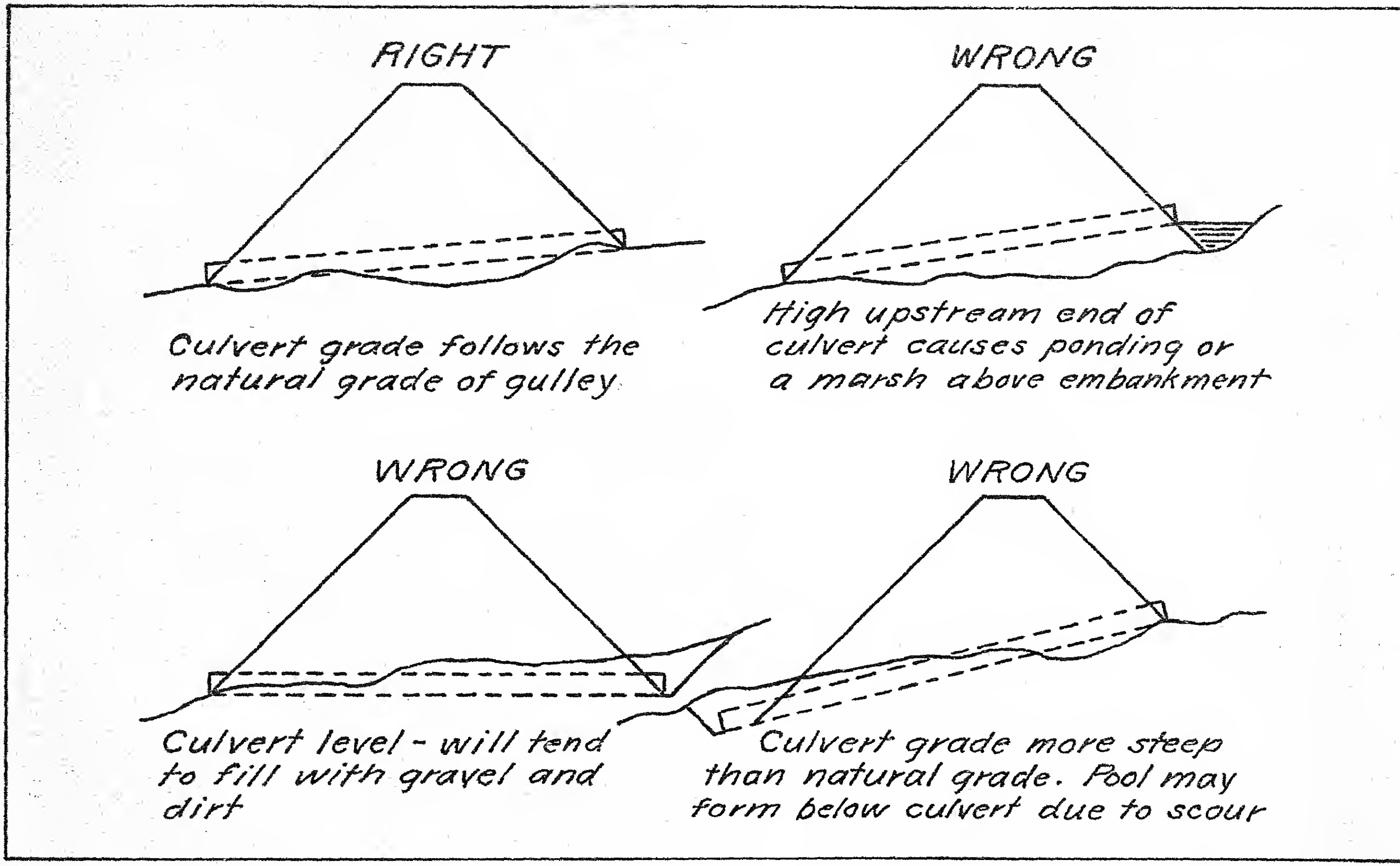



Figure 17. Right and wrong ways of placing culverts

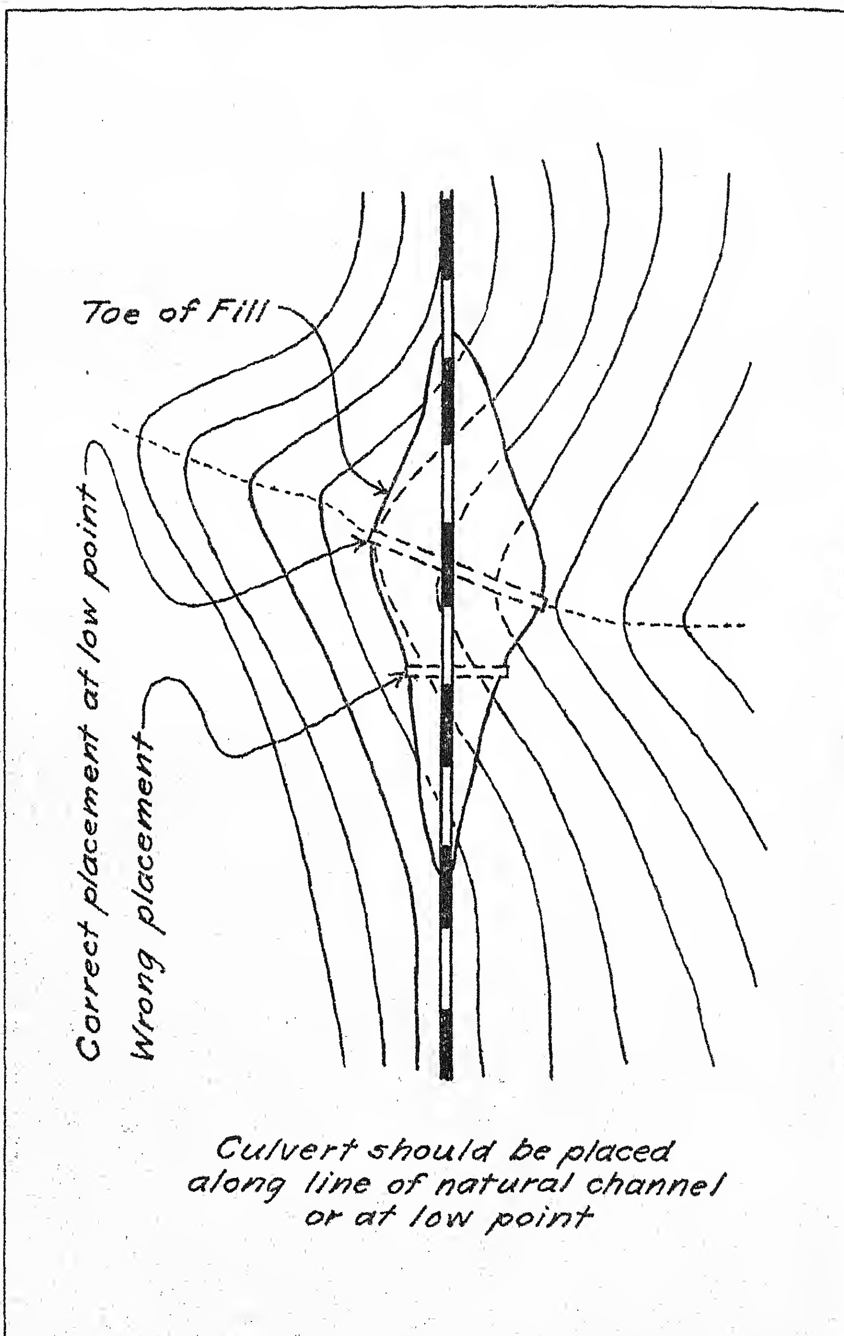



Figure 18. Right and wrong ways of placing culverts

tains can be obtained economically by a complete oiling of *all* available pools every other year, with a small amount of oiling in the intermediate years to mop up the escapes, oversights, and errors.

Drainage for control of *Aedes* species in high mountain areas should therefore be used only when it is more economical than oiling methods. This will often be the case with springy or swamp areas in mountain meadows; however, the vast number of pools on rocky ground must be handled by other methods if at all.

In some cases the raising of the water level of a lake by means of a dam and control structures will flood out mosquito breeding marshes, eliminate or greatly reduce the amount of *Aedes* breeding, and be a substantial aid to fish and aquatic bird propagation.[4]

Some mountain valleys are made by deposits of gravelly and sandy detritus formed behind the terminal morains of receded glaciers. Yosemite Valley in California is typical of such valleys. They are subject to flood overflows from their rivers during the spring melt of snow. The valley soils are usually quite porous, and as the river recedes the ground water drops rapidly and the pools drain away quickly, but usually not quickly enough to prevent the successful development and hatching of large broods of certain *Aedes* mosquitoes. This type of valley is usually long and narrow, and the overflow pools are easily drained by comparatively short laterals direct to the river. There is usually not an excessive amount of silt in the flood water so that the maintenance of such ditches is moderate in cost.

### Irrigation districts

It is a strange commentary on human intelligence that most irrigation districts have been organized, financed, and constructed without any consideration of the problem of removing the inevitable seepage and surplus irrigation water. As a result, they have been handicapped from the start by water-logged land with or without alkali, a marked increase in malaria, a mosquito pest, or any combination of these conditions. Practically all such districts have had ultimately to install a drainage system, usually for agricultural reasons but in several cases for reasons of health. The Los Molinos irrigation district, in California, performed the first anti-malaria mosquito work recorded on any irrigation district in the United States, in 1912.[5] In some districts, for example the Mesilla Valley (Elephant Butte) project in New Mexico, after agricultural drainage had been installed, supplemental mosquito control measures had to be taken.

There is a distinct difference between agricultural drainage and mosquito abatement drainage as applied to irrigation districts. Since agricultural drainage is concerned merely with the problem of lowering the ground water level to a point where crops can be raised successfully, it usually consists of large, deep main drains with comparatively few laterals. Frequently considerable quantities of mosquito breeding water remain, often in the drains themselves. Mosquito abatement drainage requires small auxiliary ditches to eliminate all pools, and uniform grades and smooth bottoms for the drains to keep them free from mosquito breeding.

On irrigated areas, in addition to the usual type of open drain or in lieu thereof, pumped wells located at strategic points may be used for drainage. These are especially useful where it is difficult to get adequate grade to carry off the water. Frequently such pumped drainage water is turned into the irrigation canals to augment the supply.

Where a hardpan lies close to the surface in a depression, seepage water may collect and cause breeding. If the hardpan is underlaid by a porous stratum, it is sometimes possible to drain such an area by drilling or digging a vertical drain through the hardpan to the porous substratum and filling the hole with gravel, crushed rock, or other porous material. In some cases a well, lined with open joint rubble, may be advisable.

The cost and difficulty of drainage on irrigation projects can be materially reduced if the excessive use of water is curtailed and seepage from the irrigation ditches is reduced to a minimum. In some districts the water is either too valuable or so limited in quantity that seepage and evaporation losses must be minimized. In these districts the principal ditches are lined with concrete and frequently the distribution is by pipes.

In some districts the ditches leak very badly in the first few years, but eventually silt up and tighten so that seepage is not important. The method of seepage control to be employed depends upon local

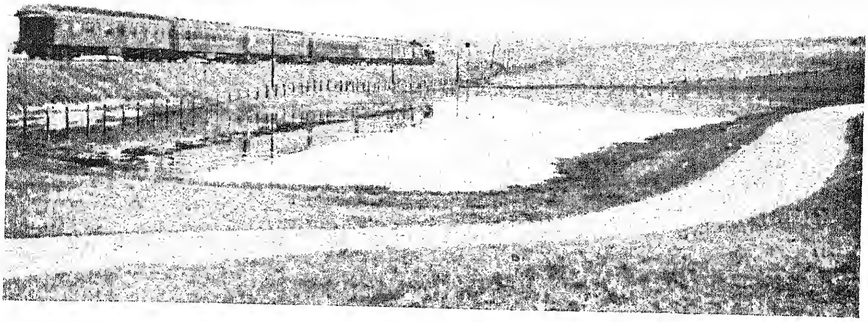


Figure 19. Ponding behind a railroad embankment, caused by an improperly placed culvert

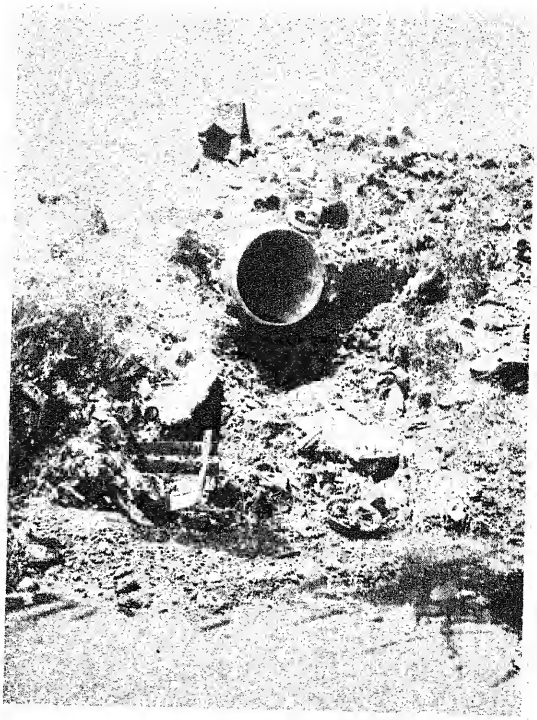


Figure 20. Upper end of a highway culvert placed too high for drainage. This results in mosquito breeding pools upstream from the culvert

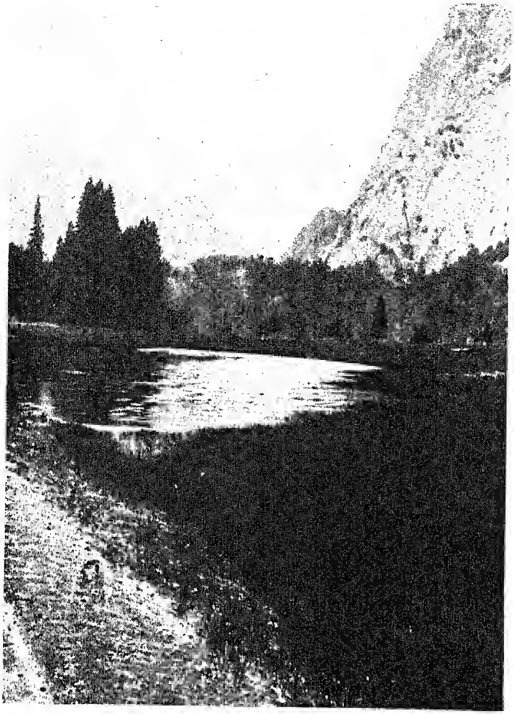


Figure 21. A typical mountain meadow mosquito breeding pool

Figure 22. Seepage water from irrigation accumulating in a low area and causing mosquito breeding

soil conditions, topography, and relative cost. Each case must be handled according to the conditions, and under competent engineering advice.

The prevention of excessive use of water is a matter partly of adequate regulation by the district and partly of education of the water user in the best methods of applying irrigation water. Frequently fields can be seen which are inadequately irrigated in the upper portions and are waterlogged at the lower end. The water at the lower end of the field may stand for a sufficient length of time to produce mosquitoes. Oiling such water may damage crops, so that ditching to remove the surplus is necessary. Such ditches should be shallow, just deep enough to remove the surplus water on the surface without abstracting any subsurface water.

Russell[6] has discussed the effects of defective irrigation in producing malaria. The following specific causes are a rearrangement of his tabulation:

1. Absence or inadequacy of drainage canals and ditches, with the resulting rise in ground water levels (waterlogging).
2. Unlined or imperfectly lined irrigation canals and ditches, with resulting seepages.
3. Undrained borrow pits, especially those with irregular bottoms, which fill from seepage.
4. Inadequately maintained canals and ditches, both irrigation and drainage, with irregular cross-section, sides or bottom, growths of vegetation, and obstructions, resulting in shallows or sluggish currents.
5. Defective regulating devices (sluice gates, etc.) which permit water to flow when and where not wanted.
6. Improper (careless) delivery of water, on to roadways, uncultivated fields, etc.
7. Absence of planned or controlled distribution of irrigation water on fields, allowing excess water to run to low areas.
8. Cutting off and leaving sections of canals, which become mosquito breeders.
9. Excessive quantities of flow in irrigation canals.
10. Irrigation drops without drain valves, causing ponding above retaining wall when canal is not in operation.
11. Improperly designed, constructed, or maintained lateral distribution devices and regulators, in which water remains ponded.
12. Unprotected canals and ditches, allowing persons or animals to break down banks.

13. Insufficient bridges over canals, resulting in unauthorized crossings by people, with resulting damage to banks.
14. Miscellaneous minor defects, carelessness, etc.

### Rice fields

Rice field areas are prolific breeders of mosquitoes, and from the nature of the case the problem of mosquito control would appear at first glance to be practically unsolvable. Here we have large bodies of shallow warm water with dense vegetation; the water may not be drained and the use of oils or larvicides is not permissible if there is any danger of damage to the crop.

A careful examination of the rice fields will show, however, that the amount of mosquito breeding in the rice paddies proper may be relatively small and the great bulk of the breeding occurs in adjacent low areas filled with seepage water.[7] Many of these principal breeding areas can be eliminated by a careful levelling of the ground surface or by the construction of small drains. The remainder can be controlled by oiling or by applying Paris green. Where there is appreciable breeding in the paddies, it may occur principally along the edges of the dykes rather than in the main part of the crop. Such breeding can be reduced by keeping the edges of the paddies free from vegetation and by maintaining a circulation of water through them.

The application of Paris green with moist sand diluent should be tried as a means of controlling larvae breeding within the paddies. It will not damage the crop[8] or adversely affect the use of fish. Under extremely difficult control conditions these measures can be supplemented by stocking the paddies with fish. In this case it will be necessary to have near by some extensive ponds suitable to breeding the fish in large quantities, so that they will be available each spring when needed. When the fields are dried up for harvesting the crop, the fish will be lost unless special measures are taken to catch them and replace them in permanent ponds for future use.

It is possible that experimentation with new larvicides, such as phenothiazine and dichloro-diphenyl-trichloroethane, may result in more effective control of mosquito breeding in rice fields.

In Portugal[9] intermittent flooding of rice fields has been made obligatory by law, as a means of malaria control.

The control of mosquitoes in rice field areas may best be described as difficult but not impossible. Careful levelling of the rice fields in addition to being good agricultural practice will be found to help greatly in mosquito control measures. The malaria-transmitting species can certainly be kept below the numbers necessary for effective transmission of the disease; the non-malarial species can be kept within such limits that they are not a serious discomfort. Eradication of either species may, however, under the usual conditions prove to be impossible or impracticable within reasonable cost limits.

Freeborn,[10] as a result of studies made in 1916–17 in the rice fields in the Sacramento Valley (California), found that about one-half of the *Anopheles* mosquitoes bred in pools adjacent to the rice fields and that they bred in outside pools for two months or more before the paddies were flooded and for another month after the water was drained from the paddies.

Geiger and Purdy[11] in 1919 expressed their experience as follows:

1. Intermittent flooding as a control measure is probably not feasible, owing to the additional cost of water and to the usual impossibility of the transfer of larvae beyond flight distance.

2. The preference shown by top-feeding minnows for the deeper, flowing water and their evident avoidance of the midfield make them a doubtful control measure. Nevertheless, they have demonstrated under experimental conditions what has been observed under field conditions in Arkansas, Louisiana and California, that their presence means a considerable reduction in mosquito larvae.

Roadside ditches containing top-feeding minnows usually show larvae very few or absent. The ditch, however, is not comparable to the rice field as an environment because of great differences in area, in abundance of obstructions for fish, and in amount of light.

3. Oil of the various varieties used in these experiments by drip-can methods proved a failure. The results obtained when used with sawdust are such that they offer future hopes for ultimate mosquito control in rice fields within reasonable flight distance of communities, and a corresponding reduction of incidence of malaria.

Purdy,[12] referring to experience in Arkansas in 1918, expressed the following conclusions:

1. Both *Culex* and *Anopheles* mosquitoes breed in about equal proportions, being moderately abundant both in rice fields and in outside puddles and ditches.

2. Mosquito breeding is about equally abundant in the interior of the rice field and along the margins and levees. . . .

4. Top-feeding minnows (*Gambusia*) placed in the rice fields at the rate of 1,400 per acre constitute a check but not a control, of mosquito production, probably because these minnows prefer the more open water along levees, and avoid the darker midfield.

5. Oil-soaked sawdust sown broadcast in the rice when plants are well grown works no apparent injury to the crop and produces an oil film that kills practically all larvae.

Horsfall,[13] studying the mosquitoes of the rice area in Arkansas, found that substantial control of *Psorophora confinnis* and *Psorophora discolor* breeding in the paddies could be obtained by planting them to a crop such as soy beans during the non-rice season, plus a thorough disking and pulverizing of the surface soil prior to rice planting. Thorough cultivation of the ground surface buries the *Psorophora* eggs in the same manner as it does *Aedes* eggs on reclaimed salt marshes.

He also found that a miscible oil (Dendrol) applied to the breeding water at the rate of four parts per million gave a one hundred per cent kill of *Psorophora* larvae, but apparently did not affect *Anopheles* larvae. It did not damage the rice crop. It is possible that any emulsified petroleum oil may act in a similar manner.

Horsfall also found that *Gambusia affinis* acted as a substantial check on the breeding of *Anopheles quadrimaculatus* in the rice fields, but did not completely stop production.

Changes in the physical character of the water in the rice paddies may effect a beneficial change in the species of mosquitoes which will breed therein. For example, we have observed in California that in rice fields where the soil is relatively porous and a considerable amount of water is required for rice culture, *Anopheles maculipennis freeborni*, a dangerous vector of malaria, bred freely. On the other hand, in rice fields where the soil is dense clay, *A. maculipennis freeborni* are either absent or relatively few in numbers, the prevalent mosquitoes being *Culex tarsalis* and *Anopheles pseudopunctipennis*. The latter species is not an effective vector of malaria in that region.

In clay fields evaporation without appreciable seepage loss concentrates the mineral content of the water until toward the end of the

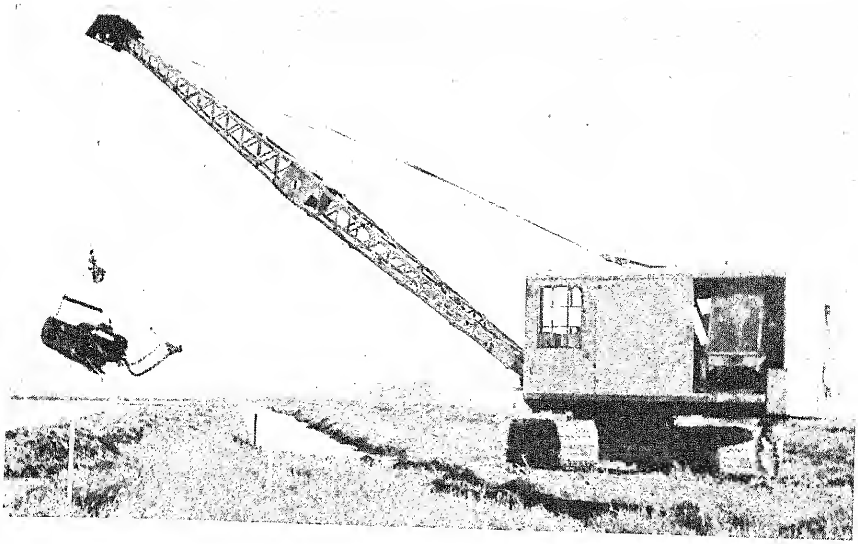


Figure 23. Tracklayer type of drag-line excavator mounted on wood "mats," excavating a main drainage ditch

*Courtesy The Macmillan Company*

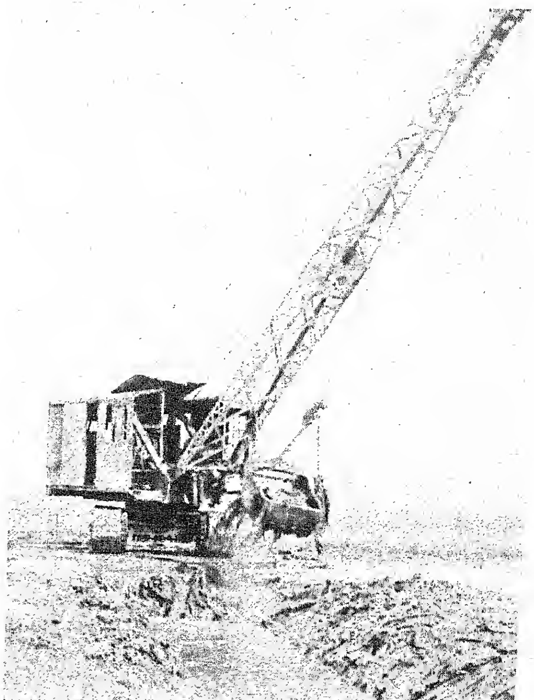


Figure 24. Drag-line excavator cutting a drain ditch into a large breeding pool

season it is quite stagnant, a condition which is unsuited to the dangerous *Anopheles maculipennis freeborni.*

If, therefore, the rice paddies in *Anopheles* regions were more carefully prepared prior to planting, and clay, bentonite, or similar material were added to porous soil to reduce seepage losses, the breeding of dangerous malaria vectors would be minimized and the savings in water requirements would probably offset the cost of remedial work. In other areas this scheme might not operate successfully, but it should be possible to make some change (naturalistic control) in the ecological condition of the rice fields so as to eliminate or minimize the production of the local disease vectors.

Robertson and Chang,[14] in studying the relation of rice culture to malaria in the vicinity of Shanghai, found that green manuring and constant cultivation which muddied the water of the rice paddies, as practiced in the vicinity of Canton, tended to reduce the production of *Anopheles hyrcanus sinensis*. They also found less production in paddies where the plants were transplanted from nursery beds than in paddies where the seed was sown broadcast.

The relation of rice culture to malaria is quite variable, due largely to the breeding habits of local *Anopheles* vectors. In the Philippines and in Malaya, for example, malaria is practically absent in the rice areas, as the vectors in these regions (*Anopheles minimus flavirostris* and *A. maculatus*, respectively) are stream breeders. In India and China malaria in rice field areas is caused principally by *Anopheles minimus*, which breeds in running streams and irrigation ditches, not in the rice paddies.

## *MECHANICS OF DITCHING*

### Equipment

Excluding from consideration river bottom and delta lands, which can as a rule be drained only by floating dredges, there are various means for excavating drain ditches. In general they include the use of the following different types of equipment:

- The power shovel
- The power crane
- Power trench excavators
- Tractor-drawn plows and scrapers
- Horse-drawn plows and scrapers
- Hand tools

The choice of means in a given instance depends upon the total quantity of excavation, the type of soil, and the cost of getting equipment on to the ground. When only a small amount of ditching is required, horse-drawn plows and scrapers, followed by hand trimming, will invariably be much cheaper than power excavation. Where large quantities of excavation are required, power equipment will be cheapest.

As a general rule, the power crane with a drag-line bucket is the most adaptable to the excavation of drain ditches of considerable length. It can be used on a wide range of soil conditions. If the surface is dry and firm but the bottom of the ditch wet or sloppy, a crane with a clamshell bucket is preferable. Power shovels as a rule are not employed for drain-ditch excavation, but a modification in which the bucket is reversed on the stick and pulled toward the chassis is sometimes used. Rather elaborate trenching machines are available which will dig ditches with side slopes. Trenching machines which dig narrow trenches with vertical sides are often not adapted to the construction of mosquito control drains owing to difficulties in clearing the sticky mud out of the excavating buckets.

For depth of a few feet tractors drawing plows and scrapers may be used economically in many cases; if the ground is soft and the drains reasonably shallow a scraper alone may be sufficient. Special scrapers have been built for mosquito districts which have been quite successful under these conditions, especially for small ditches.

Where power machinery is not economical, horse-drawn plows and scrapers may be used, if the bottom is not very soft and wet. Short ditches of small dimensions can usually be dug best by hand by means of pick and shovel. Under some conditions long-handled spades may be satisfactory but the square-point long-handled shovel is the best all-round tool for ditching. Mattocks may be found useful in some soils.

Dense vegetation often has to be cut down and cleared before ditching can be performed with any speed or economy. Heavy grass or weeds may be cut with scythe, sickle, or machete. In open fields a horse-drawn hay mower, if available near by, may be economical. For brush, either axes, brush hooks, or machete may be used. The machete, however, is a dangerous tool in the hands of a man not accustomed to it.

Dense grass and some forms of brush may also be killed by applying stove distillates or diesel oils, which are toxic to vegetation. After killing and drying, the vegetation can be burned, particularly if a sprayer is used with distillate to augment the blaze. Arsenical weed killers such as sodium arsenite or an acid solution of arsenious chloride may be used where there is no danger that cattle or other herbivorous animals will be injured. In any agricultural community the use of arsenical weed killers should be avoided.

Weed burners, constructed on somewhat the same principle as the plumber's blow torch and capable of throwing a blue flame two or three feet long, can be used for clearing dense vegetation, but the general experience seems to be that they are more expensive than other methods of clearing.

Trees, stumps, boulders, and other obstructions can be removed easily by blasting.

### Ditching with explosives

Under some conditions drain ditches can be excavated quickly and economically by blasting.[15] Where an outlet must be obtained through a rock formation or outcrop, holes should be drilled in the rock, with pneumatic drills if available, otherwise by hand drills, and the rock blasted out with appropriate explosives. The depth and spacing of holes, the type of explosive, and the quantities per hole should be determined by an experienced man, or approximated as nearly as possible by consulting a text or manufacturer's handbook on explosives. As it is definitely dangerous for inexperienced persons to use explosives, it will be good policy to employ an experienced man to direct any blasting work in rock formations.

In very wet, soft ground, ditches can be excavated by dynamite exploded by the self-propagating system, and while the dangers inherent in the handling of explosives, and particularly of detonating caps, by inexperienced persons make it advisable to employ an experienced man to direct the work, nevertheless ditches can be excavated, using this method, by inexperienced persons who are cautious and who carefully follow directions.

The best available information on ditching by explosives in wet ground is contained in the bulletin *Blasting Ditches with Explosives*, prepared (1939) and distributed by E. I. du Pont de Nemours & Co., Inc., Agricultural Extension Division, Wilmington, Delaware, U.S.A. This bulletin can be obtained also from the company's branch offices in the principal cities of the United States, and in normal times in other countries.

In water-saturated soil the shock of an exploding dynamite charge will be transmitted sharply through the relatively incompressible water in the soil and cause adjacent dynamite sticks to explode by the concussion. This is termed "self-propagation" of the blast. In this manner, provided the spacing and loading of the holes are correct for the soil condition and a correctly sensitive dynamite is used, only a central charge of dynamite need be exploded by a fuse; the rest of the charges up to certain distance limits will explode simultaneously.

If the holes are placed on line for a ditch, it can be blasted out section by section in lengths according to soil conditions. Usually it will be found practicable to limit section lengths to about 300 lineal feet, with 500 feet the maximum.

Dynamite for ditching by the self-propagating method should be a 50 per cent nitroglycerin dynamite particularly made for such work. The cartridges are usually eight inches in length and one and one-fourth inches in diameter, weigh about one-half pound each, and are packed in fifty-pound boxes.

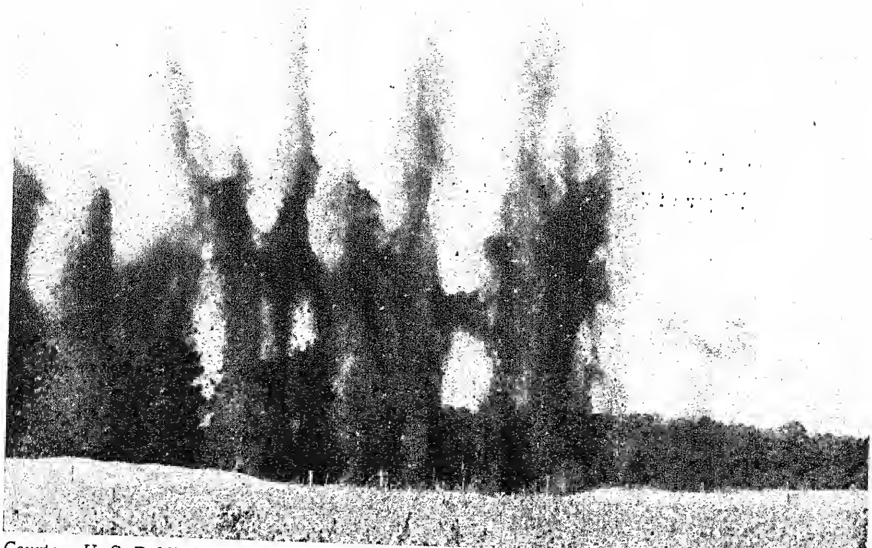
Under wet soil conditions one pound of dynamite will excavate from about one-half cubic yard (heavy soil with moderate moisture) to about one and two-thirds cubic yards (very wet soft muck), with an average of about one cubic yard per pound of dynamite.

Knowing the size (cross-section) of ditch, the volume per lineal foot of ditch can be determined if the side slope (usually about forty-five degrees) has been observed from a preliminary test blast. The proper spacing of holes and the number of sticks of dynamite per hole can then be computed approximately, and if required can be modified according to the results obtained in blasting the first section of ditch.

Comparatively narrow shallow ditches can be blasted with a single line of holes, normally spaced about eighteen inches apart for single-stick or two-stick loads, though greater spacing is often possible. Wider ditches will require two or more lines of holes and, according to the weight of earth to be excavated, will require a varying weight of dynamite per hole, with appropriate spacing. From three to five

*Courtesy U. S. Public Health Service*

Figure 25. Setting out dynamite charges to deepen an existing drain by blasting



*Courtesy U. S. Public Health Service*

Figure 26. A dynamite blast exploding to excavate a drain

*Courtesy U. S. Public Health Service*

Figure 27. Drain deepened by blasting with dynamite

sticks per hole take usually a twenty-four-inch spacing of holes; six sticks, three feet; ten sticks, three and one-half feet, and so on.

The proper depth for placing charges can best be determined by test blasts, but a rough estimate is that the bottom of the charge should be above the bottom of the ditch by a distance of about one-quarter of the total depth of ditch. Obviously, the bottoms of a line of sticks should be uniform, or an irregular ditch bottom will result.

In excavating and loading holes, the most efficient tool under normal conditions is the Ashley core punch bar (see du Pont bulletin, pp. 12–13). Wood or steel bars, or augers, one and one-half to two inches in diameter, can be used, but are less efficient. If larger holes are required, a post-hole auger should be used.

In ditching through swamps it may be necessary to do some preliminary clearing of overhanging trees whose branches might cause the blown-out dirt to drop back into the ditch. Stumps, trees, rocks, or other obstructions on line can be removed either beforehand by separate blasts or simultaneously with the main blast by additional dynamite properly placed under such obstructions.

The cost of ditching with dynamite will vary according to conditions. A ditch to drain Round Pond near Newport, Arkansas, was blasted in 1943 at a cost of $3,674. The ditch was 18,650 feet long, 10 feet wide on top, 3 feet wide on the bottom, and 3 feet deep, and drained an area of 200 acres (see *Monthly Report*, MCWA, U.S.P.H.S., September, 1943). On this basis the unit costs were twenty cents per lineal foot, or twenty-eight cents per cubic yard.

### Laying out drain ditches

Drains of any considerable size and yardage and all those to be excavated under contract should be carefully surveyed and cross-sectioned and the yardage accurately computed. The usual surveying methods familiar to all engineers should be employed. But for the smaller size ditching that plays so large a part in most mosquito abatement work, transit and level are an unnecessary and expensive refinement. A few stakes, 500 feet or more of stout chalk line or strong cotton cord for line, and a hand level with a ten-foot board marked in feet and tenths are all that is required. If a regular hand level (pocket size) is not available, a carpenter's level may be adapted.

Enough water in the bottom of the ditch to give a continuous surface makes a perfect level.

Naturally, the purpose in laying out drains is to get effective drainage at the least cost. Where the general slope of the ground is appreciable to the eye, it is usually a simple matter to follow the low points to a place where the drainage water can be directed into some natural water course or other place where there will be sufficient fall to carry it off. Laterals would then be run from the main drain by the shortest distance to connect low spots or wet areas to the main ditch. The bottom of the main drain must be deep enough for the laterals to reach all the low spots in the area to be drained. The hand level is very useful for determining these depths.

### Maintenance of drain ditches

After the drain ditch is constructed, it must be maintained in effective working order. Three main conditions making constant maintenance necessary are: 1) growths of vegetation; 2) caving or sloughing of banks; and 3) artificial obstructions.

Under some conditions growth of vegetation in and adjacent to ditches is not a problem, but as a rule ditches will require clearing several times a year in order to keep them free from obstructing growths. In tropical or semi-tropical countries the problem of keeping drains free from vegetation is most difficult and the source of considerable expense. While weed killers may be helpful under some conditions, in most cases dependence must be had on hand labor in cutting down and clearing out growths. The frequency of clearing will depend of course on local soil and climatic conditions and so the annual cost will usually be difficult to estimate in advance.

Caving or sloughing of ditch banks is apt to occur in new ditches for the first year or two. After that the banks usually become fairly stable and little further trouble is encountered, unless cattle pastured along the ditches break them down.

Artificial obstructions are as a rule frequent only in the vicinity of public roads near a city or town. It is surprising the number of people who will haul refuse away from their homes out into the country and dump it. Usually they will dump it *in* a ditch close to a road and block the ditch completely or partially. The ditch thereupon becomes a mosquito producer.

Frequent inspection of drain ditches, say at least once every two or three weeks during the breeding season, should be carried on, and all obstructions to flow, whether natural or artificial, removed promptly. During the winter all ditches should be gone over carefully and trimmed to grade and to the proper side slopes of banks, so that at the beginning of the breeding season all ditches will be in first-class order.

### Ditch lining

Under some conditions it may be desirable to line drain ditches[16] or at least to line the bottom portion of the drains. The purpose may be to maintain the ditch cross-section in ground that is unstable or easily eroded, to prevent growths of vegetation in the ditch, or to reduce the necessity and cost of maintenance.

The lining of anti-mosquito drainage ditches is not a new idea. J. A. LePrince[17] used it in the Panama Canal Zone, and it has been used more or less in the tropics[18] and in Europe. Ditches are also being lined in some of the southern states in the United States. In the final analysis, the general usefulness of ditch lining will depend upon relative cost: the initial and maintenance cost of lining compared over a period of years with the cost of maintaining unlined ditches, assuming equal effectiveness of abatement of mosquito breeding.

Drain lining materials, especially for the bottom of the drain, are usually durable materials which will resist erosion. Many types of materials have been used, including wood, concrete, asphalt, ceramics, and stone. The bottom lining (invert) and side slope lining may be either built in place or precast at a central plant and then installed in the drain. Precast units are usually economical for drains of relatively small cross-sections. They not only can be made rapidly at a central plant with relatively unskilled labor, but they also can be placed rapidly with a minimum of skilled labor.

As a rule precast units are made in short lengths (three or four feet) so that they can be easily placed by one or two men. Short lengths also have the advantage of flexibility in making curves in the alignment of the drain. For long straight ditches it is practicable and probably economical to precast inverts and slabs, reinforced with steel, in twelve-foot lengths, provided a small power crane is available to place them.

For precast inverts the shape[19] is usually the arc of a circle, with the depth about one-quarter of the top width. The thickness is usually about three inches. The top widths are usually in even feet, from one foot minimum to about six feet maximum.

For cement concrete linings, whether precast or cast in place, a well-graded coarse aggregate of hard, sound rock or gravel is required, with a maximum size of one inch. While a 1:3:5 concrete mix is often specified, this should be an approximation only. The coarse aggregate, sand and cement, should be proportioned carefully for maximum density, and the water-cement ratio and the slump kept at a point where a reasonably high-strength concrete is obtained. The minimum permissible crushing strength should be 2000 pounds per square inch at the end of twenty-eight days, and 2500 pounds per square inch is preferable. The concrete should be very thoroughly tamped in placing, preferably with a vibratory tamper, to get maximum density. Curing of concrete should also be controlled under moist conditions for several days after casting.

Where reinforced concrete is required, light steel mesh is generally used.

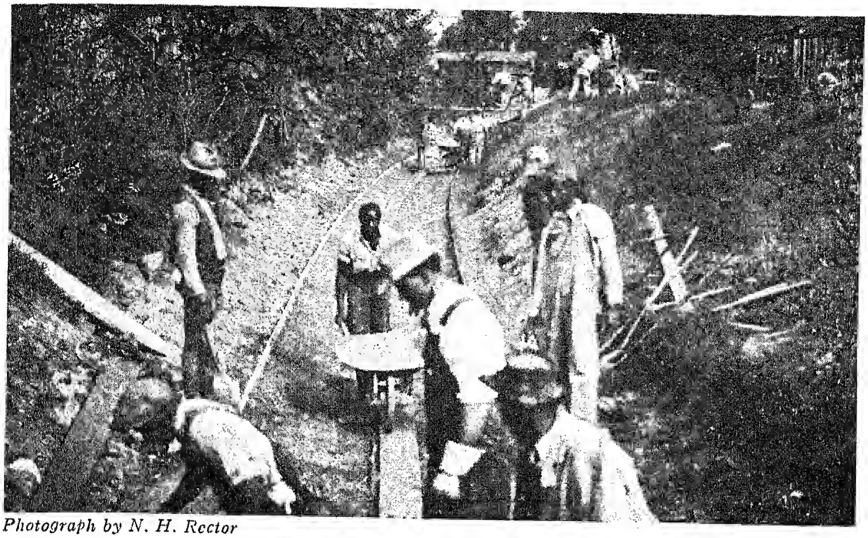
In addition to concrete, either precast or cast in place, drain linings can be made of brick, clay tile, rock rubble, asphalt or wood.

Wood linings are rather temporary, though if made of Port Orford cedar or redwood they will resist rot for many years. Well-creosoted pine will also stand up for a few years.

Fair success has been obtained with asphalt lining, using a well-graded aggregate and applying the mix hot. With comparatively sandy soils an asphalt emulsion can be applied to the soil in place, worked well into the soil, and then tamped and shaped to grade and form; such a lining is comparatively cheap, but not necessarily durable.

Longitudinal half-sections or one-third sections of clay pipe can be furnished by clay pipe manufacturers on special order, and if made of extra strength material (high temperature vitrified) are quite durable. The ordinary clay pipe may be brittle and easily damaged. Vitrified pipe linings usually cannot compete in cost with concrete linings.

Linings may be made of burned brick or flat stones. They should be set in a bed of mortar, and preferably plastered over with a one-



*Photograph by N. H. Rector*

Figure 28. Placing the concrete bottom lining for a drainage ditch

*Photograph by N. H. Rector*

Figure 29. Completed concrete lining of drain ditch bottom, with grouted brick side slopes

fourth-inch-thick mortar surface. Brick may be laid flat, with one-half-inch joints, and should be well soaked in water before laying. Stone also should be well wetted before laying. Mortar should be made of one part cement and three parts clean sand, with a little lime putty to produce good workability.

The question whether brick or rock is to be used for drain lining will depend not only upon the availability and cost of these materials, but also upon the availability and wage rates of labor skilled or semi-skilled in masonry work. In general, men of Italian, Spanish, or Pueblo Indian stock are often good natural masons, and where such labor is available at reasonable wage scales, brick or stone linings may be economical.

In general, it will be advisable to keep velocities of flow in drains above two feet per second to minimize any possible deposit of silt. In large drains, where a considerable rainy season flow occurs but there is only a small dry season flow, a small central section should be depressed in the bottom to concentrate the dry season flow, with a slightly sloping berm on each side to give the total bottom width required for rainy season flows.

Where it is desirable to line the drain above the comparatively small bottom section, flat slabs of concrete, either precast or cast in place, may be used if fairly rapid velocities of flow are probable. If the velocities will be relatively low, sodding the banks with a tough grass, such as Bermuda, will generally be a sufficient protection.

Where curves or changes in ditch alignment occur, and at junctions of drains, it is usually necessary to provide some form of bank lining, as well as bottom lining, to prevent erosion.

Whether using precast or built-in-place linings, care must be taken to have a firm, properly shaped subgrade carefully graded before placing the lining. If muck or soft mud is encountered, it should be removed and replaced with sand, gravel, or firm dirt. In very wet subsoil it may be necessary to lay an underdrain of four-inch drain tile in order to insure a stable lining.

Side slopes for drains are usually about one vertical on two horizontal, though in very firm soils one-on-one side slopes are sometimes practicable. But under some conditions the available top width of channel (especially in towns) may be relatively small, so that to get the necessary cross-section area vertical side walls of stone or concrete are needed. Under such conditions consideration should be given to replacing the open drain with a concrete, vitrified clay, or corrugated metal pipe.

Bottom linings should be provided with weep-holes at reasonable intervals according to conditions. In some soils weep-holes may be needed every ten feet; in other soils only every 100 feet. They should be about one inch in diameter; smaller holes may clog, and larger holes may wash much soil into the drain and permit caving below the lining. Weep-holes should be placed just above cut-off walls two to three inches thick and having a depth about two inches greater than the drop in grade per 100 feet.

For built-in-place linings expansion joints should be provided at about 25-foot intervals longitudinally. For precast linings expansion joints should be provided at about 100-foot intervals as a maximum.

With precast inverts the upper and lower lips of the joint[20] can be cast into the section, using special forms for the purpose, and giving about a three-inch lip. For built-in-place lining the bond between the upper and lower face of the sliding joint can be broken by laying a strip of tarred building paper on the lower lip before pouring the upper section; a groove, about a half-inch wide, left between the abutting ends of the top of the lining can then be filled with an elastic jointing compound or specially prepared jointing material.

In constructing lined ditches a template of the exact cross-section of the subgrade is necessary for good work in trimming the bottom and sides before placing the lining, and for built-in-place linings a template of the finished cross-section is necessary for good work. If strongly built, the finished template can also be used as a screed. These templates should have either a true horizontal cross-piece which can be set level transversely in the ditch by a carpenter's level, or a true central vertical axis which can be set with a plumb bob.

True grades may be set by placing stake tops on the center line of the ditch, or by measuring down from a taut line or wire set on cross boards (batter boards) above the ditch at about fifty-foot intervals.

### Underground drainage

Underground tile systems are used for drainage of agricultural lands and also of such areas as airport landing fields and athletic fields which require a surface free from irregularities. As it is considerably more expensive than drainage by open ditches, its application is limited to special cases not as a rule encountered in mosquito abatement work. Good practical descriptions of tile drainage systems may be found in various engineering texts on drainage.[2]

There are alternate measures which will more or less satisfactorily take the place of underground tile drains, usually at less initial cost. Corrugated metal pipe, perforated frequently by small holes on the under side, has been used in place of either clay or concrete pipe. It is especially useful where the ground is very unstable and flexibility is required to withstand deformation in alignment and grade.

Drains made of wood, triangular in cross-section with weep-holes bored into the lower edges of the sloping sides every few inches, may also be used. If made of redwood or Port Orford cedar, such drains will have many years of useful life; but if made of ordinary wood such as pine, they may rot out in a few years unless heavily impregnated with creosote.

Systems of narrow trenches filled to the surface with gravel or crushed rock can be used satisfactorily under some conditions, if the gravel or rock can be obtained cheaply. Where brush or trees are available, the so-called "brush" or "pole" drains are relatively inexpensive though less satisfactory. The former are trenches partly filled with coarse brush; the latter are made with slender, straight tree limbs, saplings, bamboo, and the like, laying one pole on top of two, five or nine other poles pyramided so as to leave channels between the poles.

Pole drains should be made up in sections six to twelve feet in length, the poles tied together with fiber, twine, or rope so as to maintain them in proper relative position while being placed. These sections can be butted together end to end, laying them much as drain tile would be laid.

Pole drains can take the place of pipe drains where pipe is not available and subsoil drains are required quickly. If made of bamboo they will probably last ten years or more; sapling drains will probably last only two or three years.

Pole drains, after being assembled in the ditch, should be covered with gravel if available, or otherwise surrounded and covered with coarse brush, palm leaves, or similar material to minimize clogging with infiltrating dirt.

In permanent subsoil drains, junction boxes should be provided at junctions in pipe lines. An extra inch of drop in grade should be provided at each junction. In sandy soil, junction boxes can be designed to act also as sand traps, made rectangular, one foot deep below the invert, and with a length four times the width. An opening to the surface (manhole) should be provided for cleaning out. Junction boxes and sand traps can be precast.

Subsoiling a marshy area with a "mole" drawn through the soil laterally from a main drain will, in some types of soils, particularly clay soils, improve drainage greatly but usually only temporarily. The mole is an elongated metal ellipsoid, either rigidly attached by a steel plate to a supporting frame, somewhat in the manner of a subsoil plow, or attached to the bottom of a rigid vertical cutter plate by two or three steel chain links to give the mole some degree of movement laterally or vertically.

The mole is drawn through the subsoil by a track-laying type of tractor. With a mole nineteen inches long and six inches in diameter, these drains can be put in at a rate of about three miles per hour.

R. H. Sammis[21] has had good success with a mole on the Nassau County marshes. Even after ten years these drains were still operating, though their diameter had been reduced from the original six inches to about two and one-half inches.

### Sumps

Comparatively small, shallow water marsh areas may be encountered where a long ditch to remove the surface water may be necessary. The cost of such a ditch in relation to the small area drained may be excessive, and yet the constant larviciding required by the marsh is also an expense and rather an annoyance.

In such cases it may be possible to blast out or otherwise excavate a central sump, dig a few short radiating ditches to it, concentrate the surface water in the sump and the ditches, and stock them with fish. Even if some larviciding is required, the area is greatly reduced.

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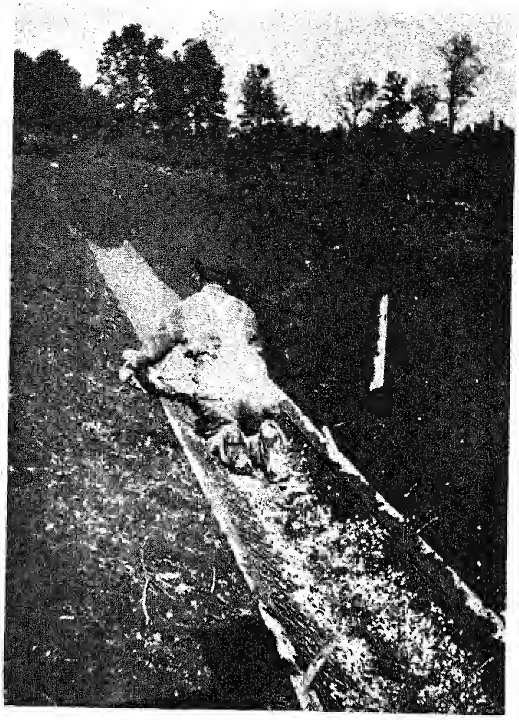
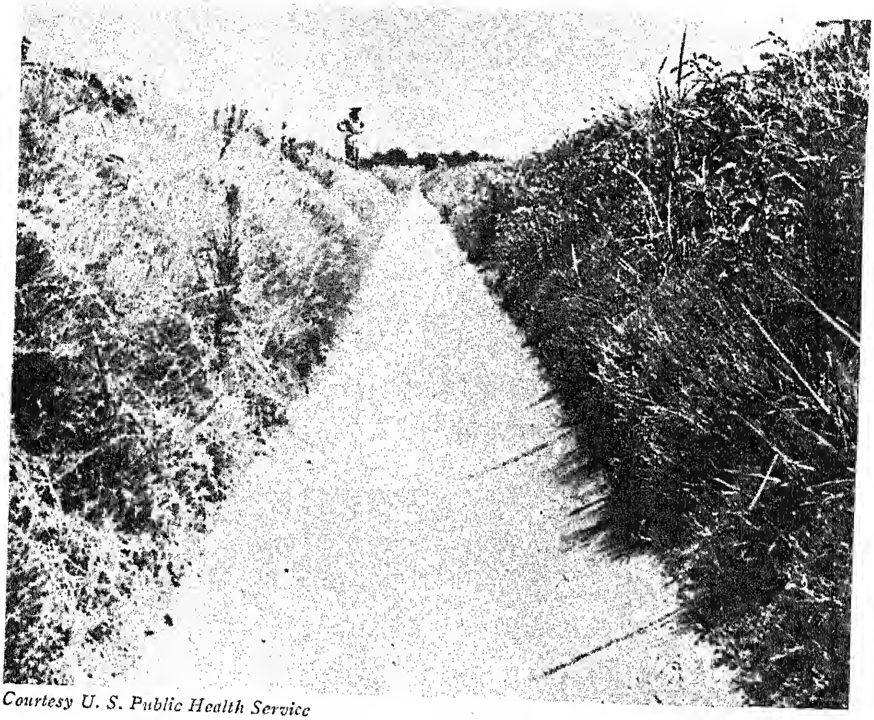
Figure 30. Placing a thin-shell concrete ditch bottom lining (one and one-half inches thick), with "chicken-wire" reinforcement



*Photograph by J. A. LePrince*

*Photograph by J. A. LePrince*

Figure 31. Sod protection of drain ditch bank above thin-shell concrete bottom lining



*Courtesy U. S. Public Health Service*

Figure 32. Precast concrete invert used as drain ditch bottom lining

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# IX

## DRAINAGE AND RECLAMATION OF SALT-WATER MARSHES

SALT MARSHES along the shores of the ocean and its various bays, sounds, and estuaries include all low lands affected by salt or brackish water and subjected to tidal action. The daily or semi-diurnal fluctuation of the water elevation is the principal feature distinguishing these marshes from the inland or fresh-water marsh. The type of vegetation is also very different.

The soil in salt marshes is usually a dense clay or very fine silt and is almost always overlaid by a porous peaty top soil varying in depth from a few inches to many feet. This peaty top soil may be of considerable depth at the heads of bays if rivers of any size enter the bay, but usually becomes thinner as the ocean is approached.

In general, salt marshes while appearing to be quite flat have a gradual slope between low tide level and the adjacent dry land. The tidal phenomena divide these marshes into two main areas which should be distinguished for mosquito abatement. In those areas which are below the normal high tide level (mean high water) and which are subjected to daily tidal action, mosquito breeding seldom occurs. On the other hand, in areas which lie between the elevations of mean high water and extreme high tides and which are only occasionally subjected to tides, there occurs practically all the breeding of salt-marsh mosquitoes.

### *CONDITIONS AFFECTING ABATEMENT MEASURES*

#### TIDAL PHENOMENA

Anyone who has salt marshes to contend with must familiarize himself with local tidal phenomena. Tides vary in different parts of the world in both range and type.[1] Three types are generally recognized: semi-diurnal, diurnal, and mixed. In addition, the so-called river type is sometimes recognized, and a "wind tide" is important in certain regions.

In the semi-diurnal type of tide there are two high and two low waters each day, the high waters being approximately of the same height and the shape of the graph of the two tides being similar. In the diurnal type one high water and one low water occur daily. In the mixed type two high waters and two low waters occur daily, but they are markedly different in height and in the form of the tidal graph. River tides show a modification of the ordinary tide due to the outflow of the river, so that the rate of rise on the incoming tide is more rapid than the rate of fall on the outgoing tide. Figure 33 (after Rude) exhibits these types of tides. In some cases, as at Manila, P.I., the diurnal tide may become a semi-diurnal tide for a few days during a month.

On the Atlantic coast of the United States prolonged strong easterly winds will pile up water against the shore, at elevations appreciably above the normal tide levels, for considerable periods of time, during which the usual tidal fluctuations may be obliterated or greatly reduced. As a result shore marshes and adjacent lowlands become flooded for weeks at a time, and drainage systems are defeated in their expected effect. Under such conditions a diffuse mosquito breeding usually occurs, and although the number of larvae per square foot may appear to be low, the great area flooded results in a large total output of mosquitoes, and may cause an appreciable pest.

Along the Florida coasts a similar situation may be aggravated by the presence of off-shore barrier reefs, which may operate to prevent normal tidal action from draining away such excessive tides, as well as the ordinary high tides.

Tides in bays or estuaries may be greatly modified by floods on the tributary river system, especially if the ocean outlet is at all restricted. Under such conditions either the tidal elevations may be temporarily increased, although undergoing fluctuations in normal sequence, or in extreme cases the tidal cycle may be completely obliterated during the maximum flood period.

Owing to the changing position of the moon in relation to the sun, the heights and depths of the tides vary during the lunar month. When the sun, moon, and earth are in line (new moon), we have high tides (spring tides); when the moon is in quadrature, at right angles to the line between the earth and the sun, we have low tides (neap tides). The so-called spring tides, one or two of which occur each month, fill the pools along the upper portions of the marshes, and in

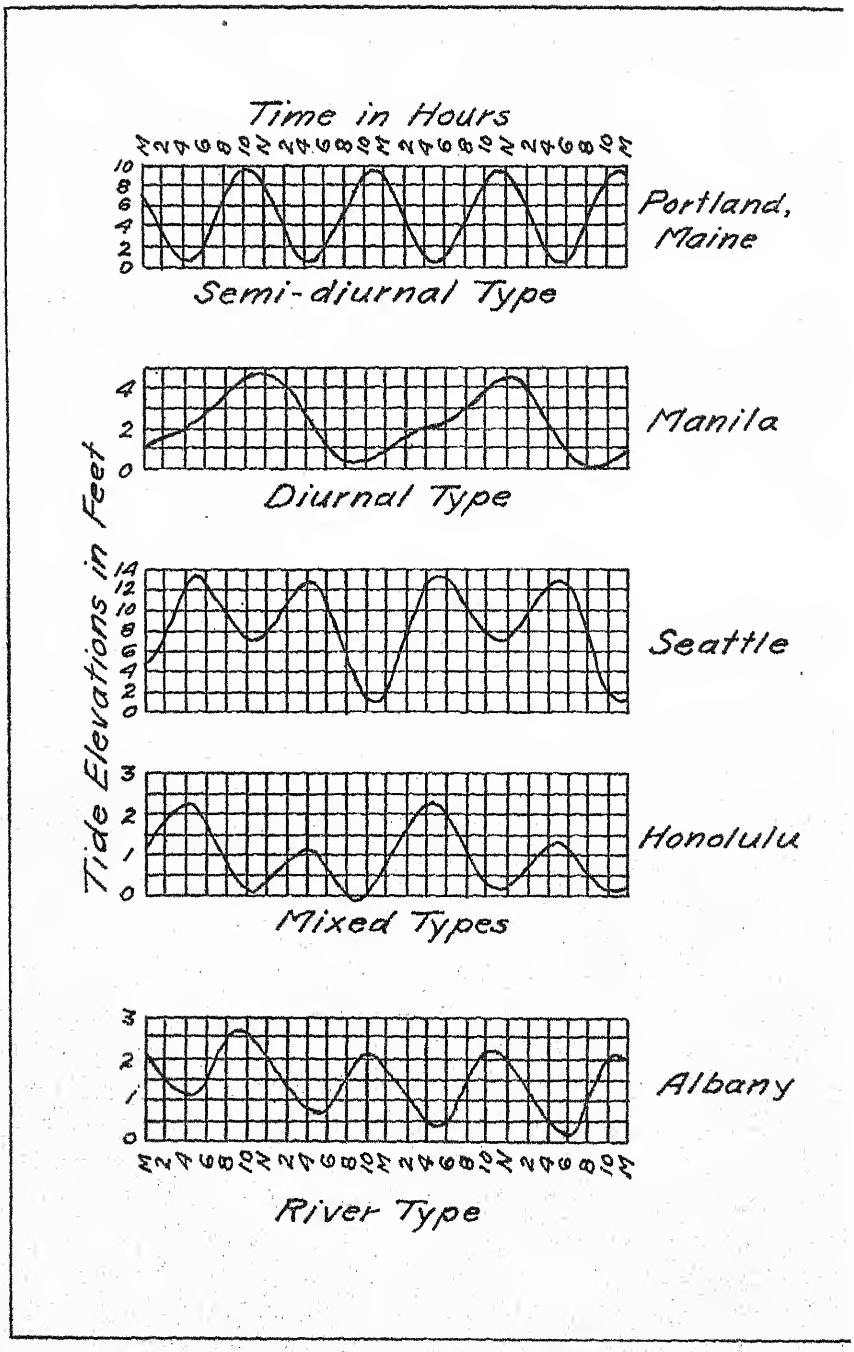



Figure 33. Tidal types. Representative tidal graphs illustrating the principal tidal forms

these pools occur the principal amounts of salt-marsh mosquito breeding.

The time and heights of the normal tides in all principal parts of the world are predicted in advance by the United States Coast and Geodetic Survey and by similar agencies in other countries. The information is published in various tide tables for the principal ports, with correction factors for time and height for secondary ports and places in the vicinity of the major ports. Any mosquito abatement agency which has a salt-marsh breeding area within its jurisdiction will need to make frequent use of the annual tide table for its area.

The dates, times, and heights of the monthly highest tides are important in their bearing on the approximate time of emergence of a new crop of salt-marsh mosquitoes. It should be the invariable practice during the salt-marsh mosquito breeding season to inspect all known or suspected salt-marsh breeding areas, beginning about two days after the highest tide and completing the inspection within six or seven days. The wait of two days is for the purpose of giving the larvae opportunity to develop to a sufficient size to be easily seen with the unaided eye. Under favorable conditions the time from egg hatching to emergence is sometimes as short as eight days; therefore the inspection, with necessary abatement measures, must be completed within that time if a flight is to be prevented.

In marsh drainage work it is also necessary to know the dates, times, and heights of both the highest tides and the lowest tides. The higher tides, if they occur during the day, will frequently make it difficult or impossible to continue ditching or ditch maintenance work. In that case the work should be temporarily suspended and the men assigned to work elsewhere. In installing tide-gates or other structures on the marsh it is usually necessary to wait for a very low tide in order to be able to do the work satisfactorily and at minimum cost.

The extreme tidal heights are also of importance in determining the heights of dykes or levees. In setting the height of dykes allowance must be made for the exceptional high tides known as storm tides, resulting from the combined effect of spring tides and high winds which tend to pile up the water on shore. River floods entering bays at the time of spring tides will also raise the high tide level.

Visible evidence of the height of these extreme tides should be looked for in each locality. After the elevation of the extreme tides has been determined, an additional height or freeboard for the dykes should be determined, which will be dependent on the probable wave height. Wave height is roughly dependent on the reach or length of water surface exposed to wind action. The formula generally used to determine wave height is

$$H = 1.5\sqrt{R} + (2.5 - \sqrt[4]{R})$$

H is the wave height in feet, and R the reach in miles in the longest straight line from the dyke which may be drawn on the water surface of the bay or harbor. The formula does not apply to exposed ocean shore line; for such situations the judgment of men familiar with the coast should be obtained.

### Types of salt marshes

Salt marshes are of two general types: ocean shore marshes and bay or estuary marshes. Depending upon the general character of the coast line, the ocean shore marshes will be either narrow, limited in area, and isolated, or extensive in area and more or less continuous. On the Pacific coast of North and South America, for example, ocean shore marshes are few and of small extent owing to the comparatively abrupt rise of the land from low water to a range of coastal hills or cliffs. Along the Atlantic coast, however, the continental shelf has a very slight rise for many miles inland and the marshes are extensive.

Ocean shore marshes present no essential difference from bay marshes, so far as control measures are concerned, except that, owing to much greater wave action, drainage outlets are more difficult to maintain, and special attention must be given to prevent wave erosion of dykes, if dykes are required. Special outlet structures or accessories to the common types of outlets are usually necessary, and far more maintenance is required on ocean front than on bay or estuary outlets.

Bay marshes are built up primarily by the silt content of the bay water deposited under shallow water conditions. This silt content is very finely divided, and as a result the marsh material consists of a mud or clay which is relatively dense and impermeable. The silt is obtained from the flood waters of the principal river or rivers enter-

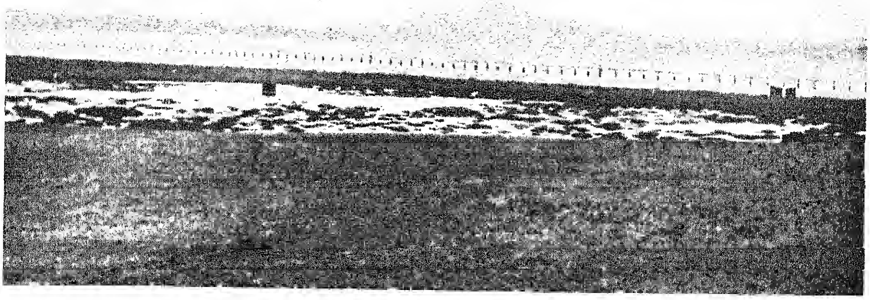


Figure 34. Typical salt marsh flooded by a monthly high tide

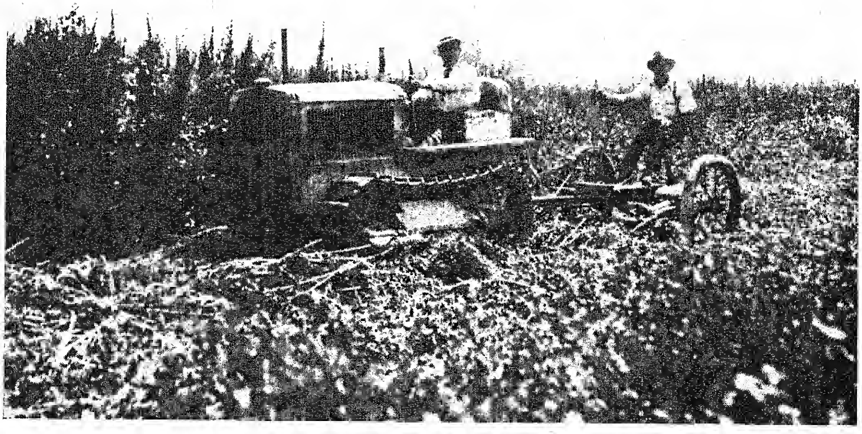


Figure 35. Cutting dense tall weeds on a marsh to permit successful oiling later when the marsh is flooded for duck ponds

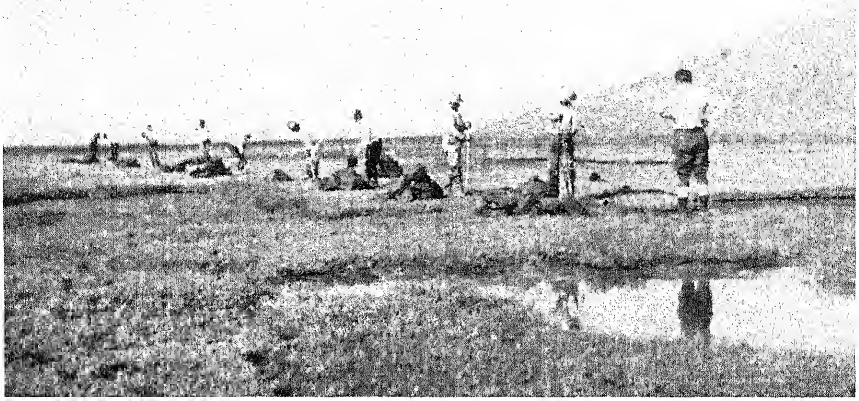


Figure 36. Laborers excavating a drain ditch across a salt marsh

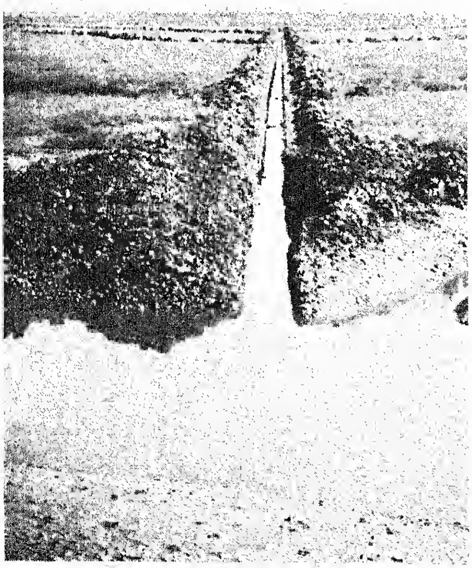


Figure 37. Hand-dug main drain emptying into a slough. Lateral ditches may be seen in the background

ing the bay. Some silt is also obtained from the flood erosion of the high land abutting on the marsh, but the principal effect of such local erosion is to deposit a relatively coarser material at the upper edge of the marsh, thus in time narrowing the marsh by elevating the landward edge. Under such conditions of deposit from local erosion it will be observed that the marsh material tends to become relatively coarser and more porous toward the landward edge, or that it may consist of alternating layers of coarser sandy material and fine silts. In such formations lateral drainage into ditches is noticeable, and drain ditches can be spaced at wider intervals.

Marshes in the deltas of large rivers that have traversed extensive flat valleys, and in the upper portions of the bays into which such rivers flow, usually will consist of considerable depths of peat or muck interspersed with silt. The peat deposits are usually found on the leeward shore, as the broken-up tules and rushes, which are the major constituent elements of peat, float at or near the water surface, and are affected by the wind as well as by the water currents. As the distance from the mouth of the river increases, the amount of peat deposited becomes less so that if the length of the bay is sufficient, the character of the marsh deposits may change from primarily peat near the mouth of the river to primarily or exclusively silt near the ocean.

The drainage or reclamation of peat marshes presents two problems: shrinkage and fire hazard. For mosquito abatement purposes it is desirable that the water level be lowered only enough to pull the water out of the breeding areas and the dense vegetation. Further lowering of the ground water level is a positive disadvantage in that shrinkage will occur, and ultimately pumping will have to be resorted to at considerable expense. Lowering of the ground water level also will expose dry peat to the danger of fire. A peat ground fire can only be extinguished by flooding, though small peat fires can be put out by excavating a trench down to wet material all around the burning area and then pumping water onto the peat, at the same time digging up the peat to permit the water to penetrate it. Fires in peat dykes can be put out only by pumping water onto the burning portion, at the same time digging into and turning up the burning peat so that the water penetrates into the burning mass.

The abstraction of water from marsh soils, and consolidation due in part to drying out of organic matter in such soils, will usually result in some shrinkage and lowering of the general ground level. This shrinkage in some cases is sufficient to make it impossible to continue the drainage by gravity and resort must be had to pumping, sometimes at considerable expense where extensive areas are drained. It will always be very desirable to make a study of probable marsh shrinkage before a reclamation project is undertaken, to determine whether pumping will eventually be required and, if so, whether the cost of pumping is justifiable. In many cases the economics of the situation may indicate that open marsh drainage is preferable to reclamation. It is reported that at some places along the Atlantic coast the use of reclamation for mosquito control has been disadvantageous because of shrinkage and the lowering of the marsh level.

In clay marshes, reclamation may cause the marsh mud to crack as it dries out. This cracking is a form of shrinkage. Under some circumstances the cracks may be several feet in depth and contain water at the bottom which will produce mosquitoes. These cracks are difficult to locate if covered with vegetation and it is always difficult and expensive to oil them. Such cracked breeding marsh can best be controlled by plowing so as to break up the surface and fill in the cracks. After the initial plowing, an occasional disking should be sufficient to keep the cracks filled.

Initial plowing will cost from five to ten dollars per acre, and subsequent disking perhaps half as much. As cracked ground can hardly be oiled for less than about four dollars per acre, and not very effectively oiled at that, and as several oilings will be required each year the economy of plowing and disking is obvious.

### Marsh vegetation

Salt marshes are usually easily recognized by their location and by their distinctive vegetation. On the Pacific coast, for example, the pickleweed, *Salicornia ambigua*, is the typical salt-marsh growth. For all practical purposes it is a correct statement that breeding of *Aedes dorsalis*, *Aedes squamiger*, and *Aedes taeniorhyncus* occurs on the Pacific coast only in association with the *Salicornia*. The growth of this marsh vegetation is in many places so thick and matted that it is impossible to obtain any effective percentage of kill of mosquito larvae by oiling methods. Under such conditions, drainage is not only more economical than oiling but is the only effective abatement measure.

J. B. Smith states[2] that on the New Jersey marshes the sedges (*Carex* species) are lowest in elevation, the three-square grass (*Scirpus americanus*) is intermediate, and the salt-meadow grass (*Spartina patens*) and the black grass (*Juncus gerardi*) grow on the higher ground. The intermediate three-square grass is typical of mosquito breeding. On the Connecticut marshes *Distichlis maritima* is characteristic of mosquito breeding.[3]

Where the growth of marsh vegetation is very thick, it is a decided handicap to thorough inspection work and makes progress across the marsh difficult and frequently dangerous. Where dense vegetation obscures cracks, holes, and small sloughs, the workmen are in danger of sprained ankles, wrenched backs, or even broken legs. A man packing a knapsack sprayer with five gallons of oil may be painfully injured by falling into a concealed crack. Knowledge of this danger causes the men to walk slowly and cautiously on marsh having dense vegetation so that the work is slowed down appreciably.

It will be found advisable, therefore, to burn off excessive marsh vegetation during the late autumn or winter according to climatic conditions. Usually it will be found helpful to use oil in knapsack sprayers to assist the fire in spots which burn with difficulty, but if a dry day with a moderate wind is selected little oil will be required except in starting the fire. The usual precautions against fire damage to adjacent property should be taken. If there are any structures (including fences) on the marsh, a clear area should be cut around them before the principal fire is started. Another caution: marshes should be burned at a time when there will be a minimum of damage to wild life. Under some conditions, if wild life on the marsh is to be preserved, it should not be burned at all.

Owing to the habit of the salt-marsh mosquitoes to lay their eggs in the mud adjacent to and under the marsh vegetation, it would seem that burning the marshes would destroy the eggs. We have found, however, no appreciable reduction in the amount of hatch after a marsh has been burned. Even after several burnings the hatch appears to be just as numerous as ever.

Aside from the marshes affected by the daily tides, there are often adjacent marshes, usually slightly higher in elevation, which are flooded only during the spring run-off or winter rains. In the San Francisco Bay region such marshes are the typical breeding places of *Aedes squamiger*, which has one annual brood in that region, hatching in early January and emerging usually in mid-March.

Shore marshes which are affected by both tidal action and stream flow from the land must be considered from the standpoint of production of certain species of *Anopheles*, as well as pest species of *Aedes*. Under these conditions a brackish marsh water may result. In the Mediterranean area this is favorable to the breeding of the efficient malaria vectors, *Anopheles sacharovi* and *Anopheles labranchiae labranchiae*. On the Bengal, Burma, and Malaya coasts, and in the Netherlands Indies islands, *Anopheles sundaicus* is an important vector breeding in brackish water. Dykes and gates which will either exclude salt water, or which will keep the marsh flooded with salt water, will help to drive out such dangerous vectors.

There are two principal methods of marsh drainage: open marsh drainage and reclamation.

In open marsh drainage, the marsh is opened up by ditches to the free ebb and flow of the daily tides so that no portion of the marsh has any standing water in which mosquitoes may develop. This type of drainage is best adapted to comparatively narrow marshes, for which the length of any individual drain from outlet to the upper end of any branch does not exceed about 2000 feet. It is also to be preferred in ground which will probably crack or shrink badly if drained dry. But where extensive areas are to be drained which involve very long drain ditches or where an agricultural or industrial use will result from drying out the marsh, then reclamation is to be preferred.

In the reclamation type of marsh drainage, the area is surrounded on the shore or low sides by a dyke. The dyke is pierced at one or more places by an outlet structure which permits water behind the dyke to run out at low tides, but which prevents any return flow at high tides. Suitable drain ditches are excavated to conduct water to the outlet structures. These ditches are normally larger in dimensions and more widely spaced than the ditches used in open marsh drainage.

The disadvantages of the reclamation type of drainage are the cost of maintenance of the dykes and outlet structures, an outlay which may be considerable under some conditions; the possible cracking of the ground, resulting in mosquito breeding which can be controlled successfully only by plowing and disking; or possible shrinkage which lowers the land to such an extent that pumping will be necessary. The advantages of the reclamation type of drainage are that on large marshes it is frequently less expensive and more effective than open marsh drainage, and it may permit the reclaimed marsh to be used for agricultural or industrial purposes.

### *OPEN MARSH DRAINAGE*

Two main types of open marsh drainage have been recognized: the pool-connecting system and the parallel-drain system. In the first, ditches are run on the shortest lines to drain the individual pools on the marshes. In the second, approximately parallel ditches are dug across the marsh, spaced at nearly equal distances.

Our experience has led us to abandon both systems in favor of a method which we believe to be more economical and effective and which may be briefly described as follows. Low areas containing water standing under dense vegetation, which are the most prolific breeding areas, are first located and roughly outlined. Wood laths may be used as markers for this purpose. The main sloughs and their branches are also followed out, trimmed, and cleared out, especially if concealed or obscured, and any obstructions to flow therein are removed. In general, it will be found economical to utilize existing sloughs and their branches as the mains of the drainage system. Loop bends may be shortened by cutting across any narrow necks. After the sloughs are located and cleared, ditches are then dug on the shortest line from the low overgrown areas and large pools to the nearest main or branch slough. If the ditch passes in the vicinity of a pool, it may be diverted slightly from a straight line to pass through the pool, or else a branch or stub ditch is connected to it, depending on which requires the least ditch. If no slough or its branch is available, a main ditch following in general the low areas, with laterals as required, is constructed to all major low spots and pools.

In laying out these ditches, minor pools and damp areas are at first neglected, until after the principal drains are put in. After the next monthly high tide occurs the area is again examined and any areas which have not drained properly are drained by small ditches.

Frequently it will be found that the main drains have made a number of projected minor ditches unnecessary, because of lateral drainage through the porous top soil of the marsh.

The spacing and position of drain ditches are appreciably influenced by the porosity of the marsh soil, especially of the top layer which is frequently peaty in character. Even where the principal marsh soil is a dense blue clay, the surface may be a layer of rather porous, partially decomposed vegetable matter together with the matted roots of marsh grasses. This layer will vary in depth from a few inches to a foot or more. The depth of this top porous layer, together with the depth of the drain ditch, controls the amount of lateral drainage effect exerted by the ditch. In general the thicker the porous top layer and the deeper the ditch, the wider will be the strip drained by the ditch. However, the top layer is seldom uniform in thickness or in porosity over any considerable area, so that the width of lateral drainage obtainable on one marsh cannot be used safely for determining the spacing of drains in another marsh which may appear to be very similar.

The depth of the drain ditches will be controlled by the elevation of mean low tide at the particular marsh in question if the tide is diurnal or semi-diurnal in character. With a tide of mixed character, the elevation of mean lower low water will be the lowest available depth for a drain. The bottom of the ditch may be approximately one foot lower than this elevation in order to provide the cross-sectional area necessary for the tidal flow.

If the rate of rise of the marsh surface toward the adjoining high land is relatively slight, in other words, if the marsh surface is very flat, the depth of the main drains may be kept at a constant level throughout so as to obtain all possible depth of drains throughout the marsh. The hydraulic gradient required to get an outflow of drainage water will then be obtained automatically by a drop in the water surface along the line of the ditch. Laterals should enter such a ditch at sufficient depth to drain the area they reach.

If the marsh has an appreciable general rise in surface to the adjacent high ground, then the bottom of the main ditch should be constructed on a grade which will give minimum excavation and still leave enough depth to drain all parts of the marsh. A surveyor's pocket hand level, used in conjunction with a ten-foot stadia rod marked in feet and tenths, is very useful in setting grades and elevations on marsh ditches. Unless a marsh is extensive, the regular surveyor's level is seldom necessary for setting ditch grades except when a contract is involved.

In general, we believe that the method of open marsh drainage herein outlined obtains drainage fully as effectively as either the pool-connecting or the parallel-ditch system and at a lower cost. It does not appreciably change the ecological balance of the marsh and in some cases, due to the improved water circulation, has been beneficial to aquatic wild life. It is, however, only suitable for work done by project employees, or by excavating machinery owned or rented by the mosquito abatement agency. It is not well adapted to contract work, except when the contract calls only for the excavation of the main drains, leaving small laterals to be constructed by hired labor.

The type of ditch required for open marsh drainage differs from the type best suited to upland drainage. In general a relatively deep and narrow ditch is best for marsh drainage and vertical banks are permissible in some marsh soils. In fact, owing to the effect of tidal flow, the marsh ditches may have their banks considerably undercut and yet remain stable and free from caving. Our practice in general has been to construct hand-dug ditches with vertical banks and then on subsequent maintenance work to bevel the upper portion of the ditch banks on a forty-five degree slope for a depth of about one foot. Frequently, when maintenance work has not been kept up, some of these ditches will be found to be completely grown over with marsh grasses but still functioning perfectly. Such neglect is not advised, however, as a minor blockage may not be easily seen. Furthermore, such a ditch is dangerous to incautious persons crossing the marsh and even to laborers or inspectors employed on the work.

Although a number of patented spades or ditching tools have been developed for hand ditching on salt marshes, our experience leads us to believe that the best all-round tool for marsh ditching is the long-handled square-point shovel, the kind that was recommended in the preceding chapter for fresh-water marshes. It is obtainable anywhere, it is cheap, and any laborer knows how to handle it. The round-point shovel is entirely unsuited to this work. The high-grade alloy steel shovels have not proved as satisfactory as the cheaper chilled steel shovels, as their life on the job is not sufficiently longer to justify their much higher cost. Workmen should be provided with ten-inch flat mill files for keeping the shovel edge sharp. In maintenance of hand-dug ditches, the hoe and the seven-tine pitchfork are useful adjuncts to the square-point shovel.

Workmen on salt-marsh drainage will require rubber hip boots on the work. The best type of boot for this work is cut longer on the outside than on the inside and the fabric of the upper portion should be close woven and non-stretching. Square cut tops and stretchable uppers are inconvenient to the workmen, as much of the work is done with the tops partly turned down. If the boot worn has a stretchable top time is lost because the workman must pause frequently to pull the boot top up. Only the better grades of boots will stand up under salt-water conditions. Cheap boots are unsatisfactory and expensive. In order to prevent excessive cutting of the sole of the boot, the upper edge of the shovel may be widened to about one-half inch by brazing or welding onto it a steel strip. After welding, the upper edges should be ground slightly to remove any sharp corners or edges.

Hand excavation of any considerable length of ditch larger in cross-section than three feet wide and three feet deep usually is not economical. Excavation machinery which is adapted to marsh drainage cannot successfully excavate a width smaller than about three feet. Therefore there is a point at which hand ditching becomes more expensive than machine ditching, which must be determined for each particular job. The controlling factors are:

1. The cubic yards of excavation three feet or more in width;
2. Cost per cubic yard of hand excavation as compared with machine excavation;
3. Cost of moving excavating machinery onto the ground, and off again;
4. Time available for the job.

To illustrate the effect of these factors and the method of analysis, let us assume two cases of marsh excavation, which for clearness of illustration are slightly modified from actual projects under our direction.

*Project A*

| | | |
|---|---|---|
| Area | | 362 acres |
| Length of drains | | 14,700 feet |
| Quantity of excavation | by machine | 11,100 cu. yds. |
| | by hand | 8,325 cu. yds. |

| | |
|---|---|
| Cost of job by machine work: | |
| Excavation, 11,100 cu. yds. at 15¢ | $1,665 |
| Engineering, supervision, transportation, & overhead, 20% | 333 |
| Moving equipment to and from job | 400 |
| Total | $2,398 |
| Cost of job by hand work: | |
| Excavation, 8,325 cu. yds. at 50¢ | $4,162 |
| Engineering, supervision, transportation, & overhead, 50% | 2,081 |
| Total | $6,243 |
| Difference in favor of machine work | $3,845 |

*Project B*

| | | |
|---|---|---|
| Area | | 56 acres |
| Length of drains | | 1,136 feet |
| Quantity of excavation | by machine | 1,086 cu. yds. |
| | by hand | 724 cu. yds. |

| | |
|---|---|
| Cost of job by machine work: | |
| Excavation, 1,086 cu. yds. at 15¢ | $ 163 |
| Engineering, supervision, transportation, & overhead, 20% | 32 |
| Moving equipment to and from job | 400 |
| Total | $ 595 |
| Cost of job by hand work: | |
| Excavation, 724 cu. yds. at 50¢ | $ 362 |
| Engineering, supervision, transportation, & overhead, 50% | 181 |
| Total | $ 543 |
| Difference in favor of hand work | $ 52 |

In Project B the hand-dug ditches could have a bottom width of two feet, but the machine-dug ditches require a minimum bottom width of three feet. In Project A part of the hand-dug ditches could have a bottom width of two feet, but the remainder, because of storm run-off quantities, require bottom widths of from three to four feet. The quantities of excavation differ, therefore, between hand and machine excavation, the latter requiring the greater yardage.

The considerably greater percentage charged for engineering, transportation, supervision, and overhead on hand-excavated jobs is in part due to the time element, hand work taking from two to three times as long as machine work. It also includes the cost of shovels, rubber boots, and similar items. The cost of moving the excavating machinery to and from the work includes freight charges and travel time to and from the equipment storage depot. On isolated projects at a considerable distance from a railroad it might be much greater than the amount stated.

It is obvious from an examination of these figures that there is a certain size of project below which machine excavation is more costly than hand excavation. This must be determined for each locality at the time of the work according to unit costs then prevailing.

Where time is an essential factor in the drainage project, machine excavation may be required in spite of its greater cost if the time necessary to get the equipment to the job is not too great.

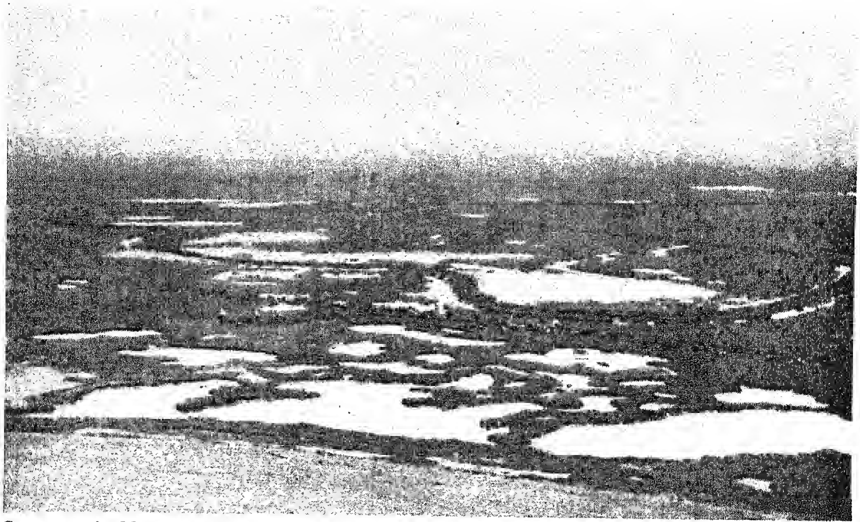
If labor is difficult to obtain, questions of relative cost may become comparatively unimportant, and power equipment must be used to get the work done. In recent years, with labor scarcity and very high wage rates, the tendency has been toward increased use of power equipment by mosquito control agencies. Small (one-fourth cubic yard) cranes with excavating buckets, power-driven ditch-cleaning machines, and self-propelled power sprayers have been especially favored.

## *RECLAMATION*

A reclamation project for mosquito abatement consists essentially of the enclosure of a tract of marsh by a dyke or levee, the installation of one or more outlet structures, and the excavation of drains to conduct surplus water to these outlets.

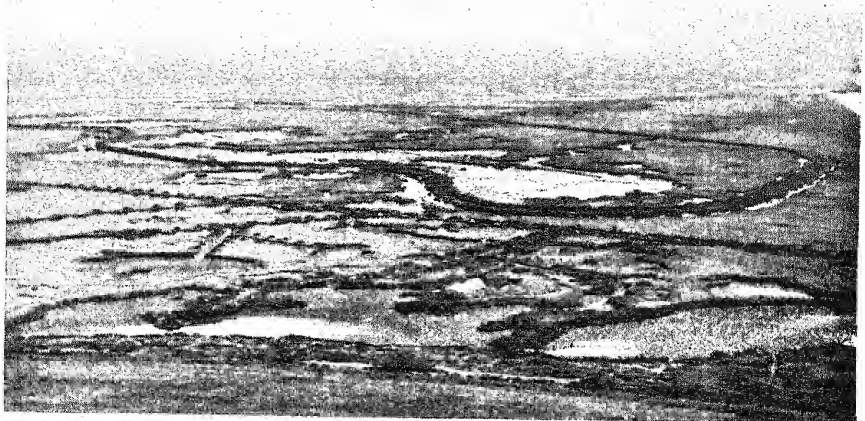
### Construction of dykes

The dykes and the main drains are constructed by excavating machinery; minor ditches may be dug by hand. Depending upon the character of the ground, either floating equipment or tractor-mounted land equipment may be used or a combination of the two types. The outlet structures will be either drainage gates or pumps, depending on topography, rainfall, flood water, or tidal elevations, and also on probable subsidence of the soil after drainage.



*Courtesy The Macmillan Company*

Figure 38. Typical salt marsh in natural condition, showing mosquito breeding pools. Drain ditches are being excavated



*Courtesy The Macmillan Company*

Figure 39. Typical salt marsh after ditching, at low tide, showing the former pools emptied

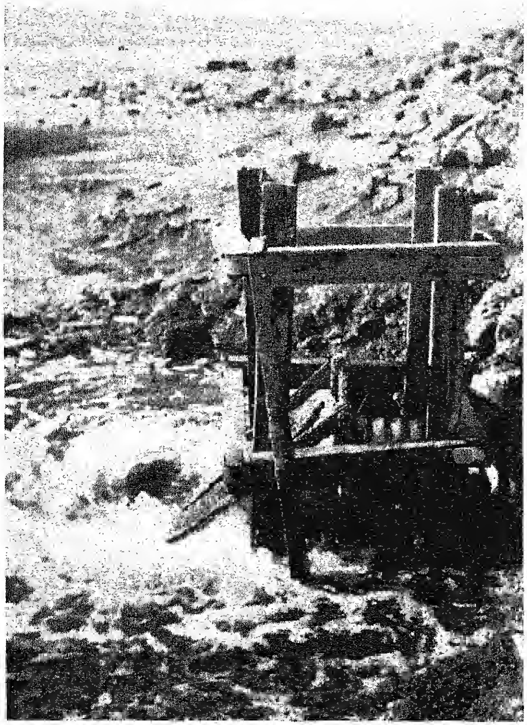


Figure 40. Automatic drainage gate (twenty-one inch diameter) discharging under full head at low tide

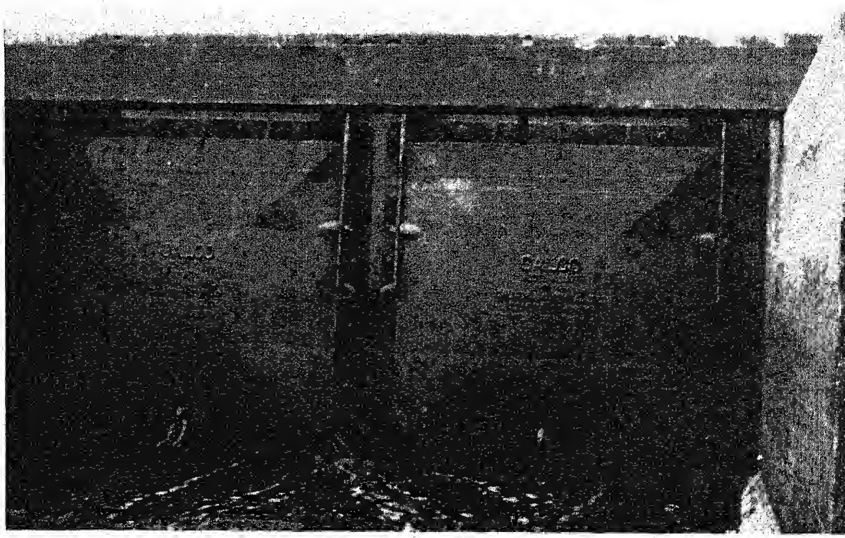


Figure 41. Two automatic drainage gates (four feet square) set in a concrete channel

The dimensions of the dyke will vary according to the character of the marsh material and the probable height of waves. It will seldom be possible to make marsh mud stand to any height greater than about six feet with a side slope of more than one vertical on three horizontal. Usually a berm will be necessary. In exposed locations and on long dykes, the top width of the dyke should be sufficient to permit a roadway along the top so that trucks can have access to all portions of the dyke in case repairs are necessary. The natural ground surface on which the dyke rests should be scarified by the dredge bucket so as to make a good bond between the dyke and the marsh surface, thus preventing seepage along the line of contact. In some soils a cut-off trench must also be dug.

The borrow-pit from which the material for the dyke is obtained should be located on the inside of the dyke; and a sufficient space should be left between the toe of the dyke and the edge of the borrow-pit so as to avoid a slump in the sides of the borrow-pit which might result from the pressure of the wet dyke material. The borrow-pit should be continuous and of uniform depth so that it can be used as the main drain ditch in the drainage system.

### Drainage outlets

Drainage outlets are structures designed to permit the outflow of water when the water level inside the dyke is higher than the water level outside and to prevent the inflow of water when the water level outside the dyke is higher than the water level inside. The structures may be either automatic in operation, or operated by hand or power (non-automatic) or a combination of the two.

The types of outlet structures vary according to the quantity of outflow water, soil conditions, the headroom or depth available, and the relative costs of materials. In general they are of the following types of construction: all metal, all wood, metal gates with concrete or wood abutments, wood gates with concrete abutments. No general rules may be laid down as to the best and most economical materials. The local cost of materials constructed in place and the probable life of the structure under local conditions must be analyzed for each locality. Local experience with each type of material is the best guide as to its durability.

The most permanent type of construction is the cast-iron gate and

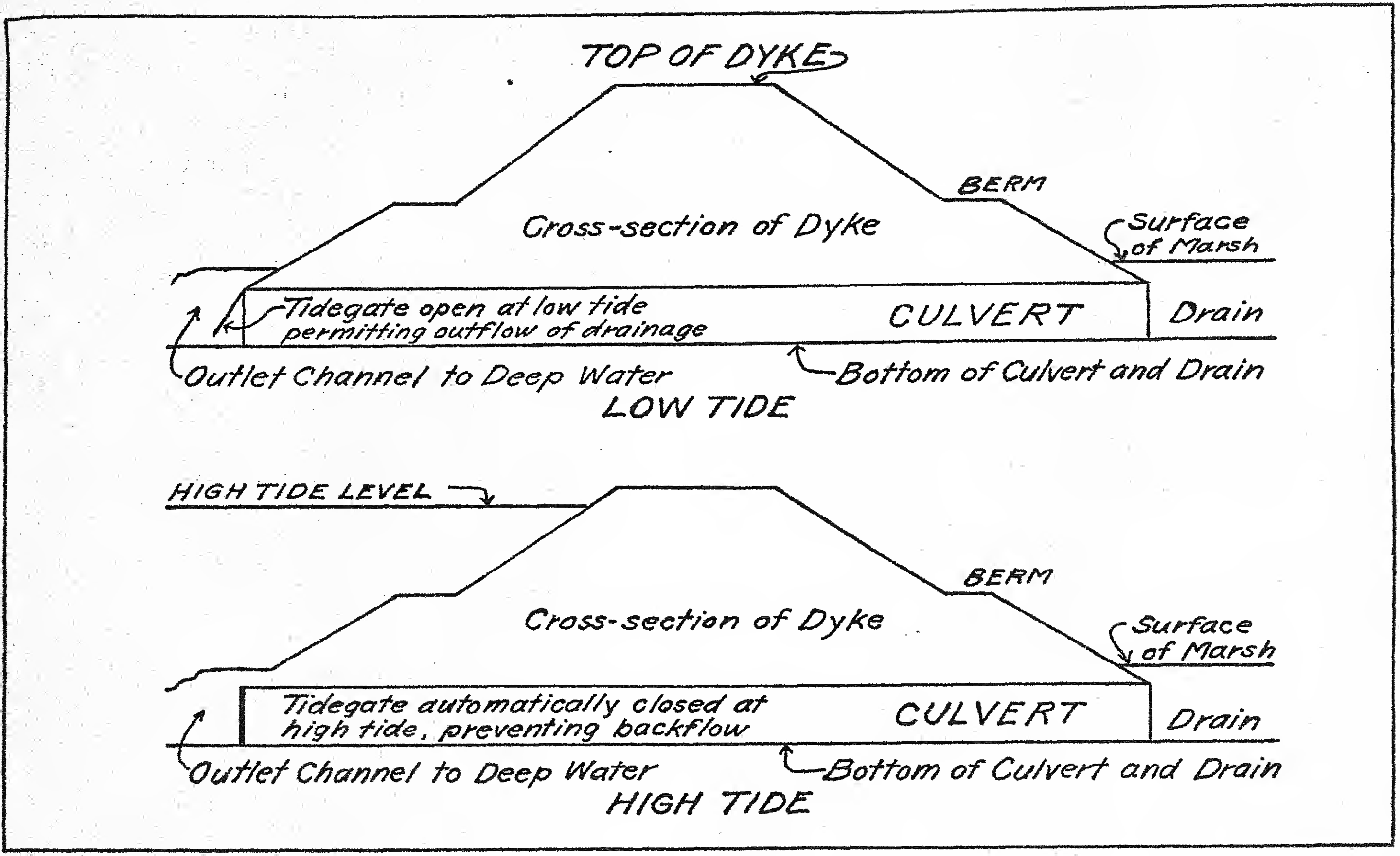



Figure 42. Diagram to illustrate action of dyke, culvert, and tide gate

frame set in an abutment of reinforced concrete. For large outlets on firm ground this is probably the best type of structure, although its initial cost is relatively high. In soft unstable ground it must be supported on piles preferably also of reinforced concrete, though wood piling may be used if the piles are cut off below the level of lower low water to avoid attack by marine borers.

Wood structures decay at the water line, and in some exposures are rapidly destroyed by marine borers unless heavily creosoted by pressure impregnation. Large drainage structures may be constructed of untreated wood if there is no danger of destruction or damage by *Teredo* or *Limnoria*. If marine borers are present, creosoted timber must be used or, better still, metal and concrete. Small drainage structures may also be constructed of wood, subject to the foregoing precaution, but for openings requiring a three foot diameter or less it is our experience that the all-metal automatic tide gate, such as the Calco model No. 100 automatic drainage gate, is the most satisfactory and economical. The life of wood structures not made of creosoted lumber will be materially lengthened by giving them a good coating of creosote paint. We have found Columbian Wood Preservative very satisfactory for this purpose and economical. As a first coat, it should be warmed and then cut with fifty per cent of distillate. All wood surfaces in contact with wood should be given a heavy coat of undiluted preservative before joining.

Metal hinges on wood flap gates are never satisfactory. Such gates should be suspended on galvanized wrought iron pipe, one and one-half to two and one-half inches in diameter, by galvanized wrought iron or bronze U-bolts. Galvanized steel pipe and bolts can be used but they will require more frequent replacement. On wood structures, nails should be galvanized and then dipped in creosote or asphalt paint just before driving. Use the heaviest nails that the wood will take without splitting.

Concrete, unless it is carefully proportioned for maximum density and thoroughly compacted in placing, tends to disintegrate on exposure to salt water. High frequency vibratory tampers are advised in placing concrete exposed to sea water.

Pure iron culverts, such as Armco iron, should not be used of a thickness less than twelve gauge on salt-marsh exposures. For sizes twenty-four inches or larger, ten or eight gauge should be used.

Metal culverts and gates should not be installed in sea water or brackish water near a sewer outlet, as the combination of salt water and sewage rapidly destroys metal structures, even attacking cast iron.

Metal culverts with automatic drainage gates or with slide head-gates should be installed in accordance with the instructions given in the *Handbook of Culvert and Drainage Practice*, published by the Armco Culvert Manufacturers Association. This handbook has much valuable information for drainage engineers. It is especially well provided with diagrams useful in computations of run-off.

Except cast iron, practically all materials exposed to salt-marsh conditions are subject to disintegration and decay. Cast iron is but little affected and appears to last almost indefinitely, unless damaged by sudden sharp blows, either accidental or malicious. Plain steel corrodes and rusts very rapidly, and even the alloy steels are attacked. Pure iron, if well galvanized and then given a good asphalt hot dip, lasts fairly well; and the new type of so-called asbestos bonded metal pipe should withstand corrosion better than iron pipe with ordinary coatings.

Usually the type of structure is to some extent controlled by the permissible depth of water behind the protecting dyke. If we assume, for illustration, that twenty-one square feet area of outlet is required to pass the maximum expected run-off and a rise of three feet in the water level behind the dyke is the greatest permissible rise, then a single drainage gate of five and one-half feet diameter would not meet both requirements, though three gates each three feet in diameter would meet both requirements.

In computing the amount of run-off to be taken care of and the sizes of drainage gates necessary, too great refinement in mathematical computation should be avoided. The rational method of computing run-off is preferred over the various run-off formulae. This is described in the *Handbook of Drainage and Culvert Practice*, and is set forth in detail in Metcalf and Eddy's *Modern Sewerage Practice*, Vol. 1, Design of Sewers (2d ed., New York, McGraw-Hill Book Co., 1928). Run-off formulae may be used, if desired, as a rough check on the quantities of water computed by the rational method.

In using the rational method of computing run-off, rainfall data for the region should be obtained and the maximum probable rate of precipitation determined. With this maximum rate of precipitation

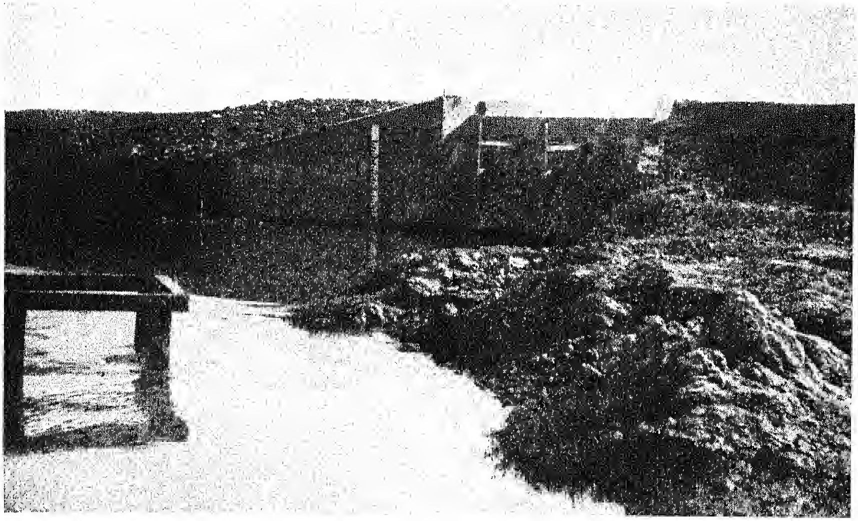


Figure 43. Large drainage gates set in concrete channel to pass flood water. Entrance vortex to twenty-one inch culvert removing residual water is seen at left

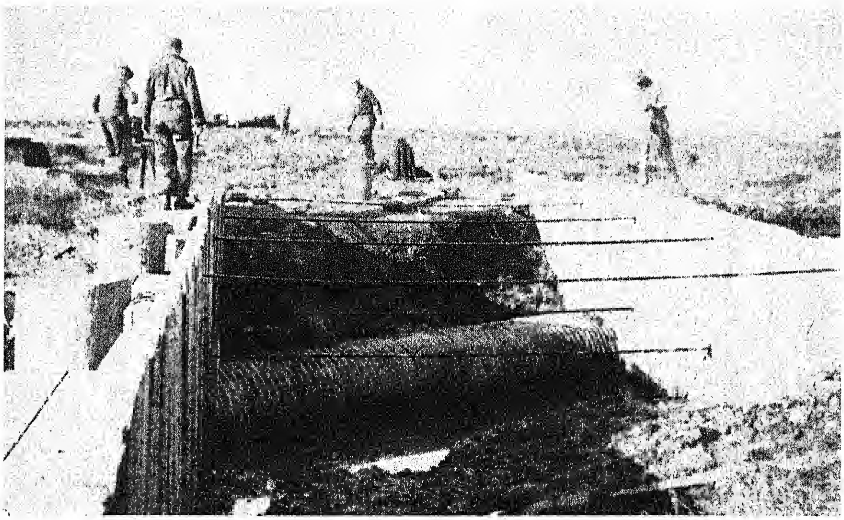


Figure 44. Corrugated metal culvert (thirty-six inch diameter) being constructed within wooden bulkheads, before being filled with earth

as a guide, the maximum run-off can be computed, using a reasonable run-off factor according to the character of the country.

On many marshes only the precipitation on the marsh itself or a small adjacent area needs to be provided for. In that case the outlet structures will be simple and of comparatively small size. It is not necessary to drain off all precipitation in one day under conditions obtaining in temperate climates. It is sufficient to get it all removed within a few days, provided the period in which the water is being removed is less than the time interval between egg hatching and adult emergence. Under tropical conditions with a rainy season, provision must be made to drain away all run-off water under the local conditions of rainfall frequency. For example, if the rainfall records show that two inches of rain per day can be expected to fall for four successive days, the outlets must be able to take care of the run-off resulting from eight inches of rainfall in four days, and to remove it all in not more than one or two additional days.

If a flood flow from adjacent high lands with an extensive drainage area debouches upon and spreads over a marsh which has been reclaimed by dykes and tide gates, it may be best to separate the flood outlet and mosquito drainage functions. The floods will have to be passed through large-area flood gates, which may be set at a higher sill elevation than necessary for mosquito drainage. A comparatively small culvert and tide gate set at the elevation of lower low water will then be sufficient to remove the residual water after the flood has passed through the flood gates.

It is difficult to keep large flood gates tight against leakage at high tide, whereas the smaller gates, particularly the circular metal gates twenty-four inches or less in diameter, leak very little unless some floating debris becomes lodged between the flap and its seat. The flood gates should therefore be set at as high an elevation of the bottom sill as can be permitted and the smaller mosquito drainage gates can be set at as low an elevation as is necessary to remove the residual water. In climates with little or no rainfall during the mosquito breeding season, the flood gates can be bolted tight or packed to prevent leakage during the dry season and unbolted or their packing removed during the rainy season.

A good deal of judgment and ingenuity will have to be exercised to get the best combination of flood gates and mosquito drainage gates under some conditions. The physical characteristics of each marsh should be carefully studied before deciding on the design of the outlet structures and, as previously indicated, their design should be based on good judgment rather than on refined mathematical computations. For example, a twenty-four inch culvert with tide gate is usually ample in size to remove residual water from 1000 acres of marsh after the flood water has passed through flood gates whose sill elevation is two feet higher than the invert of the culvert.

The type of tide to some extent controls the amount of time each day during which outflow from the marsh may occur. With a diurnal or semi-diurnal type of tide there may be nearly twelve hours in each day during which the outside water level is below the mean elevation of the marsh, and outflow is possible. With mixed type tides there may be periods of several days in which higher low water is but little below the mean elevation of the marsh, so that the only effective outflow is limited to a period of about five hours per day near the period of lower low water. These times of effective outflow, and the relative water levels at these times, must be taken into consideration in computing the areas of flood gates and mosquito drainage gates.

It is very undesirable to attempt to locate an outlet structure on an exposed shore either on a bay or the ocean as waves and wind combine to block them with silt or sand. Outlets should preferably be located on large natural sloughs near the point where they empty into the bay or ocean. In such locations any danger of silting is minimized. However, when any considerable area of marsh is cut off from tidal flow by dykes, there is an important reduction in the volume of tidal prism passing up and down such natural sloughs on each tide. This reduction in the volume of the tidal prism will cause more or less silting of the slough which must be taken account of. It may be possible to control the silting of the slough by narrowing the channel to maintain depth. A few low wing walls of three by eight inch tongue-and-groove sheet piling will often accomplish this purpose. In other cases the slough may silt up somewhat each summer, but scour out in the spring when flood run-offs occur. In a few cases, it may be necessary to dredge the outlet channel every few years in order to maintain a sufficient depth for drainage.

Dykes exposed to the action of wind and wave along bay and ocean fronts are very apt to be breached in certain places. Several methods may be used to prevent this. Wing walls of piles and heavy timber sheeting set at right angles to the line of the dyke can be used to deflect currents nearly parallel to the shore and to break up wave action unless the prevailing winds are dead on to the dyke. Riprapping with large stone or pieces of broken concrete pavement or sidewalk may also be used if available.

One of the cheapest forms of riprap for dykes is wrecked or scrapped automobile bodies. These are usually obtainable at wrecking yards in any large city, at no other cost than the haulage. They can be scattered along the exposed face and toe of the dyke. Where the erosion is severe, they must be closely packed and should extend ten to twenty feet or even more beyond the toe of the dyke. These automobile bodies perform two functions: they tend to break up waves before striking the dyke material, and to hold sand and silt and so build up the shore line. They will eventually rust away, thin sheets rotting out in a few years, but can be replaced cheaply.

Especially severe exposures, which cannot be protected adequately by wing walls or riprap, should be handled as an engineering problem under technical advice. In general, from a mosquito abatement viewpoint, it would seem inadvisable to attempt to use dykes in such circumstances, as open marsh drainage will usually be much cheaper in both construction and maintenance cost and equally effective.

It may be necessary in some cases to keep the length of the outlet through a dyke within rather short limits; in other cases, for example through dykes with very flat side slopes, a long culvert through the entire bottom width of the dyke may be relatively expensive. Either condition may be met by a short culvert with bulkheads or head walls at either end. Head walls may be less in height than the dyke, are usually constructed of concrete, and are supported on piles if the ground is soft or unstable. Bulkheads are of approximately the same height of the dyke and are tied together by steel rods or twisted cable to take the thrust of the earth fill between the faces. A long bulkhead may need additional support or stiffening by ordinary piles driven at intervals along each face. Wood bulkheads are usually built with heavy sheet piling, supported by heavy walers to which the tie rods or cables are attached.

Under some conditions floating debris may cause considerable trouble by getting under the gate seats and causing leakage. Also gates near roads or otherwise accessible may be tampered with by vandals or inquisitive visitors. To prevent this, it may be desirable to install heavy protecting screens at the ends of the culvert, especially at the gate end. Such screens may be made of heavy wires (four gauge) welded to angle iron frames and set in heavy wooden supporting walls which cannot be easily broken. The screen frames should be removable, but should be protected against unauthorized removal by means of a protective upper stringer or planking bolted to the structure so that the screen cannot be tampered with easily.

### Excavating machinery

The same general types of excavating machinery may be used for salt-marsh drainage as for fresh-water swamp drainage. (See CHAPTER VIII.)

For construction of new drains the power crane with a drag-line bucket is generally the most useful equipment and it can usually be used also for dyke construction, though in general a clamshell bucket is more efficient for the latter. For drain maintenance the clamshell bucket is more effective. For greatest flexibility of operation a power crane should have particularly wide crawler treads and interchangeable clamshell and drag-line buckets. As a rule, a floating barge with clamshell bucket is best adapted to dyke construction on salt marsh. After the dyke is constructed and the drainage gates installed, the drain ditches may be excavated with a crawler-mounted drag-line, working on wood mats. These mats usually consist of three layers of diagonally placed three-by-eight inch planks, or heavier timber for the largest equipment, heavily spiked or bolted together. The mats will run about six to ten feet in width and from fifteen to twenty-five feet in length, depending on the size and weight of the equipment and the softness of the ground. Each end of each mat has a loop of steel cable by means of which the mat can be picked up by the crane and dragged forward as the machine progresses.

Drain ditches cannot be excavated in soft salt marshes by tractors and plows as the ground will not support the tractor. After such a marsh has been at least partially drained and dried out by the major drain ditches, tractors and plows may be used in many cases for constructing the minor ditches. However, certain areas may remain too soft for machinery, and the minor ditches in such ground must be dug by hand. Frequently such ditching can be done during the winter by skilled laborers who have become useful to the organization but who would otherwise be laid off.

MAINTENANCE OF DRAINS

The same general principles of maintenance of drain ditches as were set forth in CHAPTER VIII for fresh-water drainage are applicable to salt-marsh drainage. Burning of marsh vegetation has also been discussed in that chapter.

## *CONTROLLED REFLOODING*

A relatively new method of mosquito control which has great promise of usefulness is a controlled flooding and reflooding of mosquito-producing marshes. It is a peculiarity of many of the salt-marsh *Aedes* mosquitoes, and of many fresh-water *Aedes* also, that all eggs do not hatch on any one wetting, and that some eggs do not hatch until there have been many successive wettings and dryings. It is therefore theoretically possible ultimately to hatch out all mosquito eggs in a section of reclaimed marsh by flooding the marsh at the monthly high tide, holding the water on the marsh for several days until a crop of larvae appears, and then draining the marsh rapidly before the larvae can develop into adults. The marsh is then allowed to remain dry until a subsequent monthly high tide when the process is repeated. As no adults have emerged, no new eggs are deposited. By successive wettings and dryings all eggs should be hatched eventually without any additions of new eggs.

F. W. Rush,[4] superintendent of the Solano County (California) Mosquito Abatement District, by successive floodings and drainings practically eliminated *Aedes dorsalis* breeding on thousands of acres of marsh on Suisun Bay, so that these marshes can be flooded or dried out at the will of the owner without hatching any appreciable numbers of mosquitoes. From seven to ten successive floodings and drainings were necessary to accomplish a practical elimination of hatchable eggs. His experience was probably the most extensive and successful with this method of control but we have had success with it on certain marshes on San Francisco Bay. We have also found that repeated oiling (which killed the larvae and prevented the deposit of new eggs) practically eliminated within about six years all mosquito hatching on salt marshes behind dykes which had inadequate drainage structures and were subject to flooding in winter.

A modification of the method of controlled reflooding and redraining has been used by the Matadero Mosquito Abatement District[5] near Palo Alto, California. This is a form of flood control on dyked marshes subject to inundation from rain water run-off from the adjacent terrain. In this method the flood water is held up to a level sufficient to give boating depth throughout the marsh, and maintained at that level, as nearly as possible, by operation of the outlet gates. Docks are constructed at convenient points accessible by truck, at which the boat can be loaded. The entire area is then oiled by a power sprayer mounted in the boat.

This modification is applicable where the available hydraulic grades are insufficient to remove the flood water completely, so that considerable areas of residual water are left after the flood waters subside, into which the mosquito larvae would concentrate and be difficult to get at. By raising the water level and maintaining a high level, the larvae are more vulnerable to attack by boat-transported power sprayers. The overall cost of this method should be compared with the overall cost of pumping out the residual water by the use of portable pumps, to determine its relative economy.

The rapidity with which controlled reflooding can be carried out depends upon the availability of large volumes of water for flooding. With tidal water available the control cycle may be completed within one or two years; where rainfall is required for flooding it will depend on the caprice of the weather.

Successful use of the method also depends upon adequate structures for the rapid removal of water after it has remained on the ground long enough (two or three days) to hatch out all the eggs which will hatch on that wetting. The entire amount of retained water then must be removed within two or three days and the larvae swept out into open water where they will perish, be eaten by natural enemies, or prevented by rough water from emerging as adult mosquitoes. It is advisable, if not essential, to oil any residual water which contains larvae or pupae after the redraining has been finished.

After a marsh has been cleaned of eggs by this method, it is still necessary to keep it under observation so that a reinfestation will not be built up by the escape of adult mosquitoes in small residual areas on that marsh, or by reseeding from adults hatched on near-by marshes.

We believe that this method of control is deserving of far wider application than it has had, and that it will effect appreciable economies in mosquito control. It should also be possible to make use of this method for the control and eventual elimination of flood water species, such as *Aedes vexans*, by various modifications according to the species of mosquito and the type of terrain involved.

It is interesting to note that some *Aedes* eggs are capable of surviving in a dry state for a considerable length of time. N. M. Stover, superintendent of the Three-Cities Mosquito Abatement District (San Mateo County, California), reported to us the case of a marsh, in a controlled area, which had been dry for about ten years and was then accidentally flooded. Thereupon the output of *Aedes dorsalis* was as large as normal.

The process of hatching *Aedes* eggs has been elucidated by Gjullin,[6] Reeves,[7] and others. Apparently a reduction in the dissolved oxygen content of the water in which the eggs are immersed is the actual hatching stimulus, and mere wetting does not cause hatching. This explains the sudden hatching of eggs of flood water *Aedes* species, such as *Aedes vexans* and *Aedes lateralis*, in a few days after the floods have subsided. The decomposition of the accumulated vegetable matter in the residual pools lowers the dissolved oxygen content of the pool water, causing hatching. This hatching will not occur in water of high oxygen content during flood stages of the river.

### *CONSTANT LEVEL FLOODING WITH CIRCULATION*

Under certain conditions it is desirable or necessary to keep a marsh flooded, for example, if the marsh is a duck club preserve. Reasonably satisfactory mosquito abatement can be maintained if the following requirements are met:

1. The water level is maintained at a constant elevation;
2. The marsh is kept well stocked with *Gambusia* or other larvicidal fish;
3. The fish have access to all parts of the marsh;
4. The water is kept in circulation.

These requirements can be met by enclosing the area within a dyke and furnishing a sufficient supply of water in any one of several ways. Fresh-water ponds can be kept fresh either by a diversion from a stream, or by pumping from a well. In either case there must be an excess of inflow water over the evaporation and percolation losses; otherwise in time the saline content of the pond water will increase until it is quite brackish or even salty.

Ponds on tide water can obtain circulation by holding the water height at about mean tide elevation by means of weirs at the inlet and outlet structures. An inlet structure, consisting of a weir and a culvert with automatic tide gate, reversed so as to permit inflow at high tide but no outflow at low tide, should be installed at a point on the dyke furthest upstream with relation to the tidal flow. The outlet structure, also consisting of a weir, a culvert through the dyke, and an automatic tide gate, should be installed at approximately the opposite end or side of the marsh, nearest to the downstream side with reference to the tidal flow. The outlet tide gate should permit the discharge of surplus water at low tide, while preventing inflow at high tide.

The marsh area should then be adequately ditched so that fish can have access to all parts of the flooded area. There must be no isolated areas into which the fish cannot readily penetrate. The inlet and outlet structures must also be provided with well-built screens (quarter-inch mesh), which should preferably be in duplicate on removable frames so that they can be easily removed for inspection and repair. The flooded area should then be stocked with *Gambusia affinis* or other larvicidal fish. If the water is brackish or salt, *Gambusia* which have been adapted to brackish water should be planted if they are obtainable.

On the first flooding of such an area either larvicide or oil should be used to abate the first (and usually very large) hatching of mosquito larvae. Thereafter the constant level of the water, plus the activities of the fish, should prevent further development of mosquitoes.

The success of this type of mosquito control depends on keeping the inlet and outlet structures and their screens in good working order, the area well stocked with *Gambusia* or other equally effective larvicidal fish, and the marsh in such condition that the fish always have free access to all parts of the flooded area.

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# X

## FILLING, PUMPING, AND FLUSHING

In addition to naturalistic methods and control by drainage, there are three abatement measures of first importance, directed against the production of mosquitoes: 1) filling or 2) pumping out wet areas, and 3) flushing small streams or channels.

### Filling small wet areas

In any mosquito abatement project there will always be found certain low wet areas which cannot be economically drained by ditches or because of lack of elevation cannot be drained at all. Usually these areas are comparatively small; many are simply small holes of a few hundred square feet. Obviously it would be highly expensive to dig several hundred feet of deep ditch to drain an isolated hole of, say, fifty square feet. The interest on the cost of such a ditch might easily exceed the annual cost of oiling the hole. However, oiling is a procedure which should be avoided whenever reasonably possible and so some other means should be used to handle such cases.

If the hole or pond is permanently filled with clean water, it may be stocked with larvicidal fish. But frequently such holes become foul or unsuited to fish life and with the disappearance of the fish may breed mosquitoes.

The best and most satisfactory method of handling such areas is to cure them permanently by filling in level with the surrounding terrain. If the hole is small this may be done by hand shoveling; holes of intermediate size may be filled with a horse-drawn scraper if there is a high spot close by from which fill can be obtained.

In some cases it may be necessary to haul fill material, but in those cases the cost will mount, possibly to an excessive expense. However, in the vicinity of cities, especially during an active construction season, free fill may be obtained if the haul is not too long by arranging with building contractors to dump excavated material in the areas to be filled. Low areas in or near cities can, also, sometimes be filled with rubbish, street sweepings, and the like. In such cases earth should be used as the final cover, as a rubbish fill may have numerous voids containing water.

In constructing drainage ditches with power equipment, it will usually be found possible to fill low areas close by the ditch with the material excavated at no additional expense. This should always be kept in mind and carried out.

### Sanitary fill

Municipal garbage and refuse have been used successfully by various cities as a fill material for breeding marshes. The elimination of mosquito breeding is in such cases a by-product of a garbage disposal method, usually described as a sanitary fill, or the fill and cover method. The garbage fills are covered with a layer of earth so as to reduce the fly and rat nuisance which would be extreme if the garbage were not well and promptly covered. The city of Berkeley, California, has for a number of years used the sanitary fill as a garbage disposal method, and in doing so has reclaimed more than thirty-five acres of mosquito breeding marsh along the waterfront.

### Hydraulic fill

The most permanent fill for salt marshes is that made by hydraulic dredges, but the cost is usually prohibitive. The dredges suck mud and sand from the bottom of the adjacent bay and pump the mud and water mixture through a pipe to a discharge point on the marsh. The discharge point is shifted from time to time to keep the fill near the desired surface elevation. The water may or may not be retained by a low dyke to settle out fine mud.

At fifteen cents per cubic yard, which is about as low as medium size projects are likely to be priced for average ground in normal times, such fill would cost about $720 per acre for three feet depth of fill. With very soft mud the price may run as low as eight cents per cubic yard. But even at this price the cost is unjustifiable for mosquito abatement. However, when harbor or channel improvements are being made by hydraulic dredging and areas are needed for the disposal of the excavated mud, it may be possible to arrange with the dredging contractor and with the owners of adjacent marshes to have the excavated mud deposited on the breeding marshes without cost to the district or at a price not exceeding the annual cost of maintenance of drainage for that marsh, capitalized at the prevailing rate of interest.

### Pumping

Pumping becomes necessary under several conditions on reclamation or drainage projects. The first, obviously, is when the general land level of the drained area is at or below the low water level of the adjacent river or bay. The second is when a drained area, especially in peat or muck soils, has shrunk or subsided below the adjacent water level. Other cases may also occur in which the capitalized annual cost of pumping is less than the construction cost plus capitalized maintenance cost on an expensive outlet drain ditch.

Major pumping projects are matters which should be in charge of hydraulic engineers skilled in the field of drainage pumping. Special types of pumps for large quantities of water at low heads have been designed, which are best adapted to reclamation projects, but so many variables enter into the problem that engineering talent in that particular field should be called upon for advice.

### Portable pumps

Aside from projects which involve the installation of a fixed pumping plant, cases may occur where portable pumping units will be useful. For example, a low area which is filled only by winter or spring rains and for which an expensive drainage ditch would otherwise be required can be handled economically by pumping after the spring rains. Other cases are low areas temporarily filled by accidental water, such as water from a broken water main or the backing up of a clogged sewer. In cities, also, when underground street vaults of the various public utilities, especially the telephone company, fill up with water, a portable pump can be used; and in rural districts, when water accumulates behind highway and railroad culverts placed at too high an elevation.

Three general types of portable pumps are available:

1. A small pump operated by a gasoline motor and portable by two men
2. A small centrifugal pump mounted on the front of the auto truck, and driven direct by the truck's engine
3. A larger type of pump (up to six or more inches diameter discharge) mounted on a trailer.

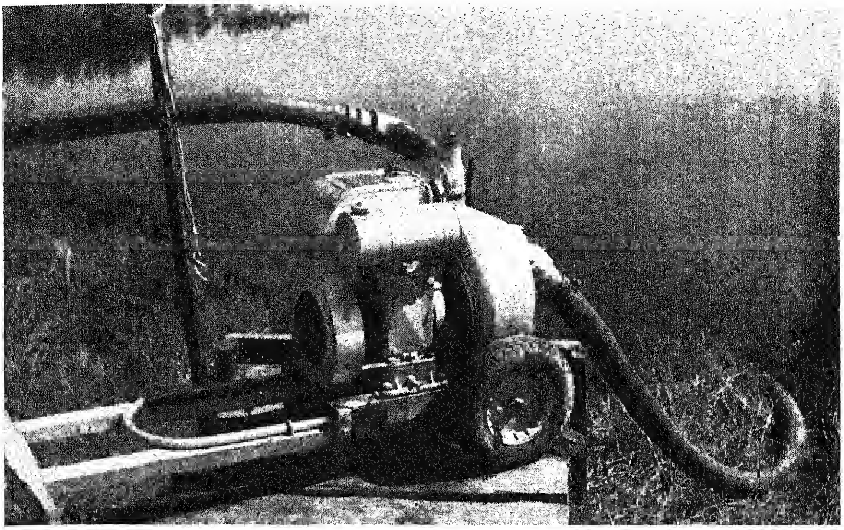


Figure 45. Portable centrifugal pump (three inch diameter discharge) driven by gasoline engine. It is useful in pumping out low areas which do not drain readily

Figure 46. Small centrifugal pump (one and one-half inches) pumping out a small marsh

Photograph by J. A. LePrince

Figure 47. A gate to impound water for flushing a ditch

Photograph by J. A. LePrince

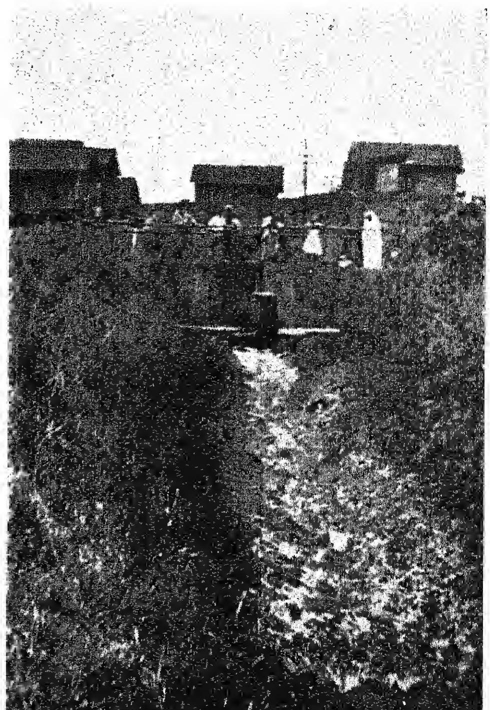


Figure 48. Removal and destruction of mosquito larvae and matted algae in a ditch by flushing

The best type of portable pump can only be determined by studying the requirements of a particular project. On some projects a fairly large pump may be needed; on others a small pump will be adequate. Again, on some projects the pump, mounted on a truck or a trailer, can be hauled to the areas which need to be pumped out; on other projects the points at which pumping is required are accessible only on foot.

We have had fair success with a two inch centrifugal pump directly connected to a two cylinder two-cycle outboard type gasoline engine. It pumps about 10,000 gallons per hour against a five foot head. Outside of the natural "cussedness" of a two-cycle engine, it has been reasonably satisfactory over a wide range of conditions. Care must be taken to keep fine debris in the marsh water from clogging the foot-valve strainer, and especially the strainer on the pipe to the water-jackets on the engine cylinders; or an expensive repair bill may result. This pump, with ten feet of two and one-half inch suction hose and seventy feet of two inch discharge hose, and fittings, cost (in 1933) $181. It is easily carried by two men.

We have had better success with a three inch contractor's type pump, or trash pump, which does not clog easily, is self-priming, and, as the engine is air-cooled, avoids trouble from the clogging of strainers on the water-cooling system. The four-cycle gasoline engine is also a decided advantage over the two-cycle. This pump, mounted on a frame with two pneumatic tire wheels, can be handled by two men even over rough ground without too much difficulty, and on soft marsh can be moved by laying wood planks for a runway. It cost (in 1938) $440 complete with suction and discharge piping.

Contractors' pumps can be obtained in a considerable range of makes, sizes, and capacities, with both gasoline engine and electric drive and with several types of mounting for convenience in moving about according to the requirements of a construction job. The smaller pumps may be mounted either on skids or on a frame with two wheels. Pumps five inches or larger in size (the size rating is the diameter of the discharge pipe) are usually mounted on four-wheel trailers.

Manufacturers give tables showing the capacity of pumps for various heads (in feet) against which the water is to be pumped, and on request will give information concerning gasoline consumption or wattage at different heads and capacities. The three inch pump we are using at present uses about three-fourths gallon of gasoline per hour, pumping about 22,000 gallons per hour against a head of about twenty feet.

Because the water to be pumped may contain a large amount of mud and trash, portable contractors' pumps have impellers with relatively wide passages and are ruggedly built to withstand hard use and even abuse, a factor which is more important for this type of service than high hydraulic efficiency.

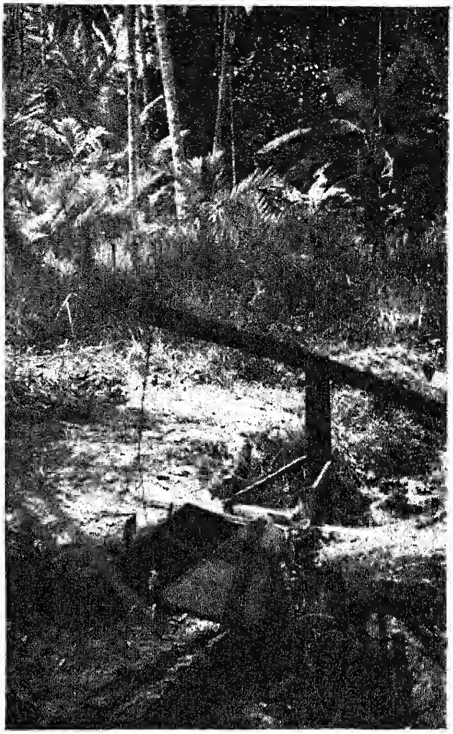
The United States Public Health Service[1] in 1943 drained a marsh near Macon, Georgia, where gravity drainage was impossible, by means of a two-inch portable centrifugal pump. Approximately three acres were unwatered in eight hours. The benefits were a 95 per cent reduction in inspection time, and the practical elimination of a major breeding place of *Anopheles quadrimaculatus*. Prior to pumping, an average of twenty-seven pounds of mixed dust (about two and one-half pounds of Paris green) and six man-hours were required for larviciding: after pumping, less than one pound of dust and only a few minutes of time were required for each inspection.

### Flushing small streams

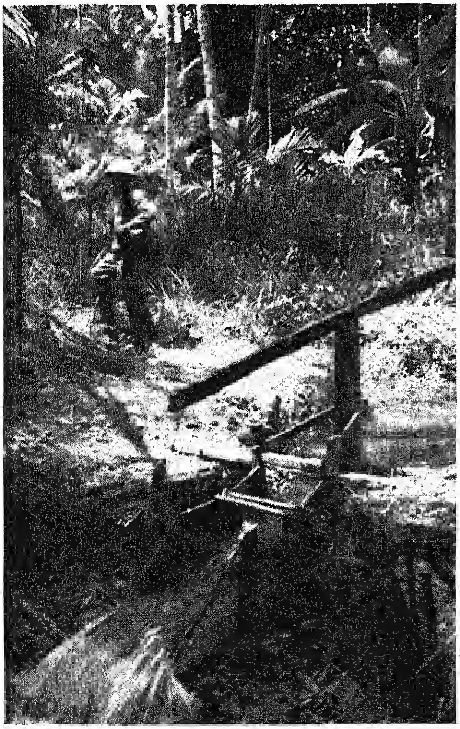
Under some conditions the intermittent discharge of relatively large volumes of water (flushing) is a useful and successful method for the control of mosquito breeding in minor streams and channels. Some vectors of malaria are typical stream breeders, such as *Anopheles maculatus* in Malaya. The larvae of this species are equipped with special hooks which enable them to hold on to the sides and bottom of running streams. This species, and also *Anopheles minimus* and *Anopheles fluviatilis*, which breed in running water, as well as such species as *Anopheles superpictus*, *Anopheles culicifacies*, *Culiseta incidens*, and other species which typically breed in stream-bed pools, can be either stranded, or destroyed by the wall of water developed by the flush, or transported beyond the limits of the protected zone, or carried into a lower stream section unsuited to their development or containing their natural enemies.

In many cases the simple act of transporting the larvae by the flush beyond and outside the protected area suffices for local disease

Figure 49. A wooden tilting bucket, counterweighted, for automatic flushing of small streams. Bucket in raised position, accumulating flush water behind dam

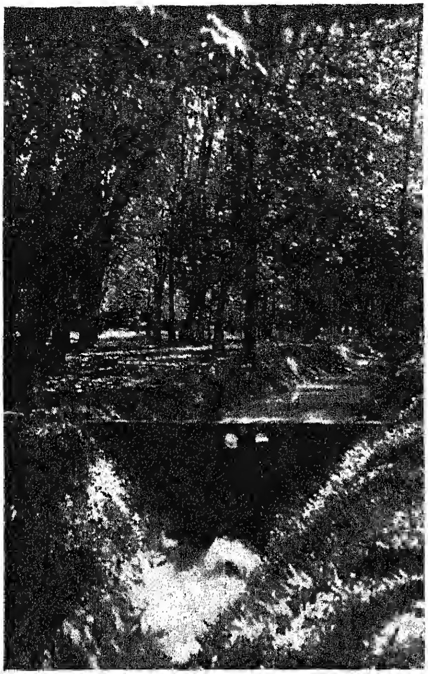


*Courtesy Sir Malcolm Watson*



*Courtesy Sir Malcolm Watson*

Figure 50. A wooden tilting bucket, counterweighted, for automatic flushing of small streams. Bucket in lowered position, discharging flush water



Courtesy Sir Malcolm Watson

Figure 51. A concrete dam with de-Villiers type siphon, discharging water automatically to flush a drain

Courtesy Sir Malcolm Watson

Figure 52. A small earth dam with oil-drum culvert outlet and hand-operated wooden gate, for stream flushing

control, even if the larvae are not killed. If simple transportation of larvae outside a protected zone is all that is necessary, the volume of the flush need not be great provided it gives sufficient variation in the stream flow to flush out all pools and eddies. The variation in flow above the flushing structure also appears to have a marked effect in reducing mosquito breeding. The destruction of larvae caused by the flush is not well understood but may be the result of the dynamic effect of the water disrupting their bodies, or perhaps the result of battering them against solid objects in the stream bed. In many situations stranding of the larvae above the normal flow level may be an important factor in their destruction.

Flushing devices may be operated either manually or automatically; where practicable, automatic flushing is preferable. Essentially, a flushing device consists of a dam or weir across the stream, to accumulate a relatively large amount of the flow during a period of a few hours or days, plus a discharge gate or apparatus which can very rapidly discharge the accumulated water in a large volume traveling down the stream at high velocity. After discharge the device must be closed by hand, or must automatically reset itself, so as to begin the accumulation of water for the next flush. The quantity and rate of flush should be regulated so as not to cause property damage along the stream or channel. Signs should be posted to warn persons passing along the stream. The steeper the gradient of the stream bed and the larger the volume of flushing water, the further downstream will be the distance this control measure will be effective.

The quantity stored above the dam, and the rate of discharge, should also be so regulated on streams or channels in alluvial or other erodible soils that the flush does not exceed the quantity carried by the stream under normal flood conditions. The purpose here is to avoid excessive erosion of stream banks.

If an automatic flushing device is used, it is desirable to place in the dam a manually operated sluice gate, which may be used for three purposes: 1) to flush out silt and gravel accumulations above the dam, which may reduce the available storage quantity or even interfere with the operation of automatic discharge devices; 2) to pass at least a part of the excess flow during floods; 3) to discharge what water is available above the dam at times of very low flows when insufficient water accumulates to operate the automatic devices on a sufficiently frequent schedule.

If the dam is of permanent construction, care should be taken to provide an overflow spillway, either over the entire length of the dam or over a sufficient length to pass any probable expected flood flow safely. The overflow section should be so designed as to prevent excessive erosion at the toe of the dam, which might undercut it and thus cause its destruction.

Under some conditions it may be wise to build temporary earth dams with simple discharge devices, which will operate during the dry season but be washed out during the rainy season. In parts of Malaya and India such simple dams (Figure 52), using fifty-five-gallon steel barrels with both heads cut out as the culvert and with a wood gate, have been cheaply installed. The barrels and gate are attached by a wire to a tree on the bank, and so are recovered when the floods come in the monsoon.

Probably the simplest automatic flushing device is the counterweighted tipping bucket (Figures 49 and 50). It can be made cheaply of lumber, and at more cost but more neatly of sheet metal. In this device, when the water rises high enough on the slanting apron of the bucket, the weight of water overbalances the counterweight, the bucket is forced down, rotating on its hinges, and the dynamic effect of the discharge holds it down until the discharge is nearly complete. Thereupon the upward pull of the counterweight overcomes the velocity pressure of the flowing water, the bucket is raised, and the accumulation of water begins again.

The width and water depth in the sluice channel and tilting bucket will determine the rate of discharge of this device. We do not know of any measurements of discharge on this device, but would expect a bucket two feet wide, with a two-foot initial water depth, to discharge at an initial rate of about fifteen cubic feet per second.

The type of automatically operating flushing device most frequently used is based on the siphon principle. Williamson[2] and de-Villiers[3] have developed such devices very effectively on the hill streams of Malaya and have devised structures which can be constructed quite cheaply. Somewhat similar devices have also been used in the Philippine Islands.[4] Such siphons can be improvised out of a steel oil drum, with one end cut out and inverted to form the bell, and with metal pipe for water discharge and vacuum release (Figure 51).

Macdonald[5] developed a small automatic siphon fabricated of reinforced concrete sections at a central depot and distributed to the tea estates in Ceylon at a price of twenty-five rupees. Each siphon discharges about 475 imperial gallons per minute, the height of dam being about three feet. Several siphons can be installed in the same dam to increase the quantity of flush where necessary. A single siphon with a reservoir capacity of 3000 gallons has been found sufficient to cleanse a stream bed two feet wide on a very flat slope for from one-half to three-quarters of a mile in distance.

Worth and Subrahmanyam[6] experimented further with precast or "block type" siphons, which in completed units were three feet nine inches long by four feet three inches high, and at two and one-half feet head discharged about three and one-half cubic feet per second per square foot of opening. They also experimented with an improved "funnel" type of siphon, cast in place on the site, and incorporating an auxiliary inspirator siphon which slightly increased the vacuum. This type discharged about five and one-half cubic feet per second per square foot of opening at thirty inches of head.

They concluded from their observations that the velocity of flush in the stream bed should be a minimum of 1.75 feet per second for successful cleaning out of larvae from the stream bed. To control a stream bed for a distance of 5000 feet, at various slopes, they found the following areas in square feet of siphon discharge opening to be required:

| SLOPE OF | WIDTH OF STREAM IN FEET | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| STREAM | 10 | 20 | 30 | 40 | 60 | 80 | 100 | 150 |
| 1 in 50 . . . | 0.47 | 0.94 | 1.41 | 1.88 | 2.82 | 3.76 | 4.70 | 7.05 |
| 1 in 100 . . | 0.67 | 1.34 | 2.01 | 2.68 | 4.02 | 5.36 | 6.67 | 10.05 |
| 1 in 200 . . | 0.94 | 1.88 | 2.82 | 3.76 | 5.64 | 7.52 | 9.43 | 14.14 |
| 1 in 400 . . | 1.33 | 2.66 | 3.99 | 5.32 | 7.98 | 10.64 | 13.33 | 20.00 |
| 1 in 600 . . | 1.63 | 3.26 | 4.89 | 6.52 | 9.78 | 13.04 | 16.33 | 24.50 |
| 1 in 800 . . | 1.88 | 3.76 | 5.64 | 7.52 | 11.28 | 15.04 | 18.88 | 28.32 |
| 1 in 1000 . | 2.11 | 4.22 | 6.33 | 8.44 | 12.66 | 16.88 | 21.08 | 31.62 |

Ramsay and Anderson,[7] working in Bengal, found that siphons of about four times the discharge capacity of the Macdonald type siphons were better adapted to their conditions. They also found it necessary to control by oiling the breeding which occurred in the reservoir above the dam. The following equations for estimating the quantity and rates of flush required for a stream bed are based on their findings:

Let Q = rate of flushing in stream bed in cubic feet per second
W = width of stream bed in feet
D = depth of flow (average) in feet
V = velocity of flow, in feet per second, required to control mosquito breeding
C = average rate of discharge of one siphon in cubic feet per second
M = number of siphons
K = available quantity, in cubic feet, of water stored in reservoir above the dam
T = total time of flush

Then $Q = WDV$

$$Q = CM$$

$$T = \frac{K}{Q} = \frac{K}{CM}$$

Note: 1 cubic foot per second = 448 U.S. gallons per minute
= 374 imperial gallons per minute
1 cubic foot = 7.48 U.S. gallons
= 6.23 imperial gallons
1 imperial gallon = 1.2 U.S. gallons

The velocity of flow, V, in the stream bed will depend on the average longitudinal slope of the stream bed and its roughness, as primary factors, and also upon the quantity of flush and the shape of the cross-section of the stream bed. In general Ramsay and Anderson found a velocity of one mile per hour (88 feet per minute, or 1.47 feet per second) to be the minimum effective rate of flush; higher velocities probably will be found to be more effective.

In computing the velocities of flow in a stream bed channel, the simpler Manning formula is to be preferred to other more complex formulae. It is:

$$V = \frac{1.486}{N} R^{2/3} S^{1/2}$$

$$Q = A V$$

where

R = hydraulic radius of the cross-section of flowing water in the stream bed, which is the cross-sectional area of flow, A, in square feet, divided by the wetted perimeter, in feet, of the cross-sectional area of flow

S = the longitudinal slope of the stream bed (drop in elevation, in feet, divided by the length, in feet)

N = a coefficient of roughness, which for natural streams will range from about 0.030 for straight reaches with smooth sides and bottom, through about 0.055 for stony and gravelly bottoms, to as much as 0.150 for shallow streams with irregular bottoms and sides badly overgrown with brush and vegetation.

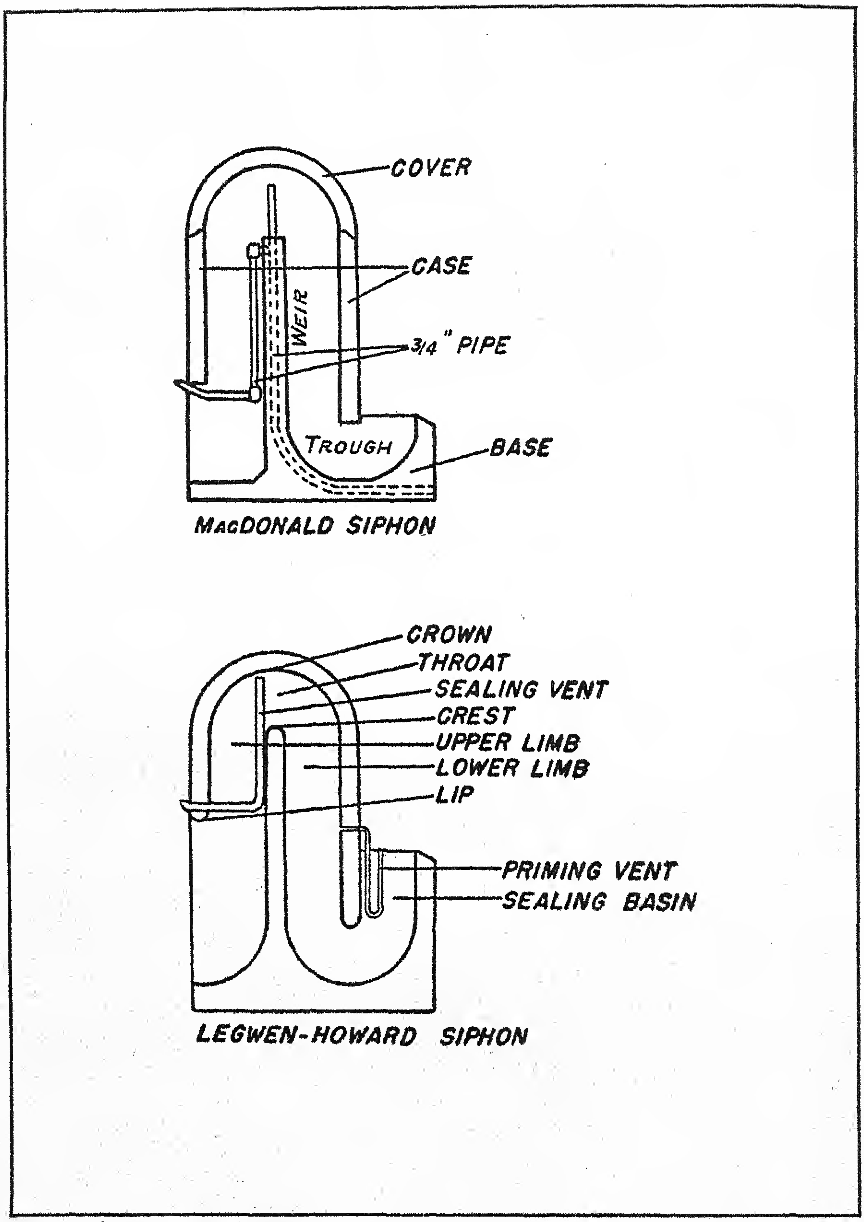
Legwen and Howard[8] have developed an automatic siphon with improved hydraulic characteristics, reducing the preliminary leakage of water during the priming period, and shortening the time required to produce full flow through the siphon. In the Legwen-Howard siphon, full flow usually takes place in less than one minute from the release of air in the priming vent, and the siphon effectively seals and resets itself in readiness for the next cycle. Figures 53, 54, 55, 56, and 57, reproduced by permission, give details of design and construction of this improved siphon.

A series of tests run on this type of siphon, fabricated of sheet metal and having a water channel cross-section (discharge) area of 108 square inches, indicated rates of discharge as follows:

| *Head in inches* | *Discharge rate in gallons per minute* |
|---|---|
| 10 | 525 |
| 15 | 650 |
| 20 | 775 |

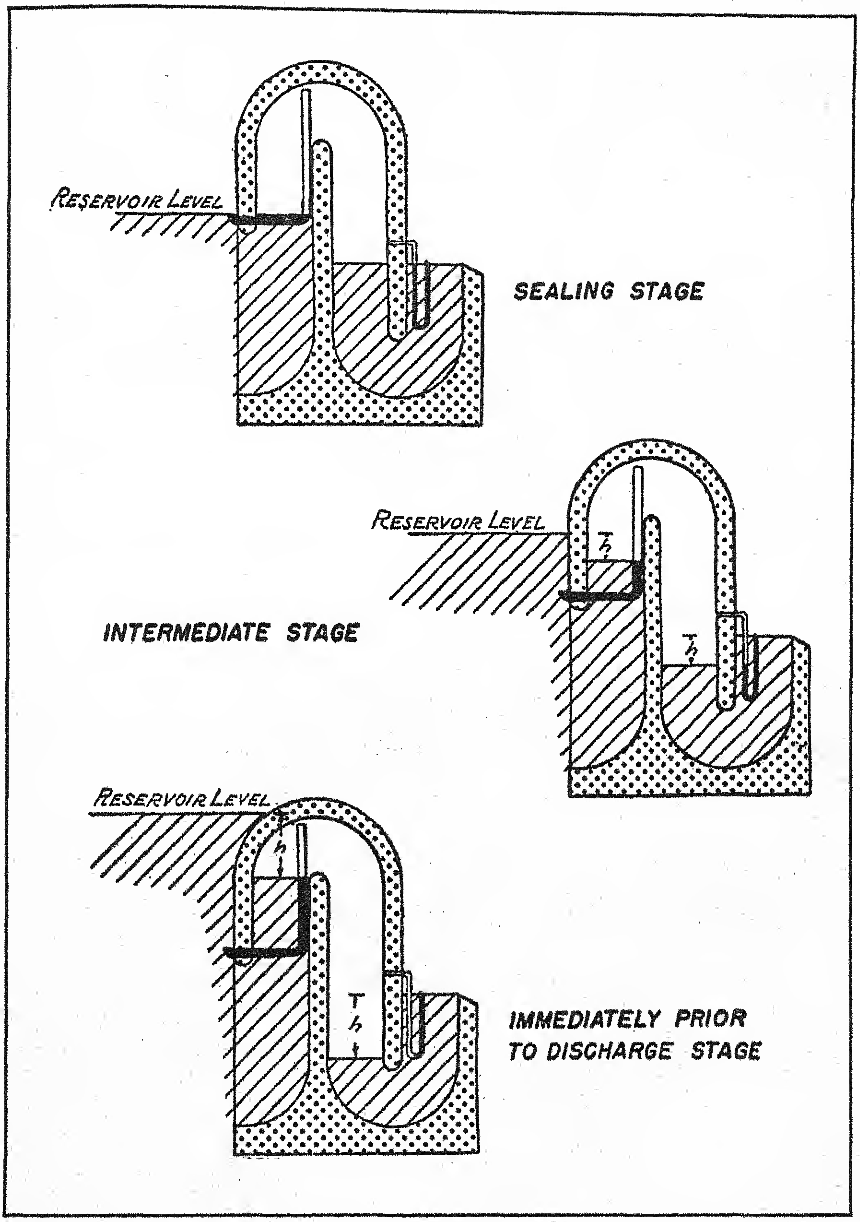
Recently a precast concrete siphon of the same size, but with improved streamlining of the interior, and with a one-fourth-inch diameter sealing vent instead of the regular three-fourths-inch sealing vent, has been tested by Legwen, with the following observed rates of discharge:

| *Head in feet* | *Discharge rate in gallons per minute* |
|---|---|
| 1.2 | 1,020 |
| 1.5 | 1,180 |
| 1.8 | 1,310 |
| 2.1 | 1,460 |



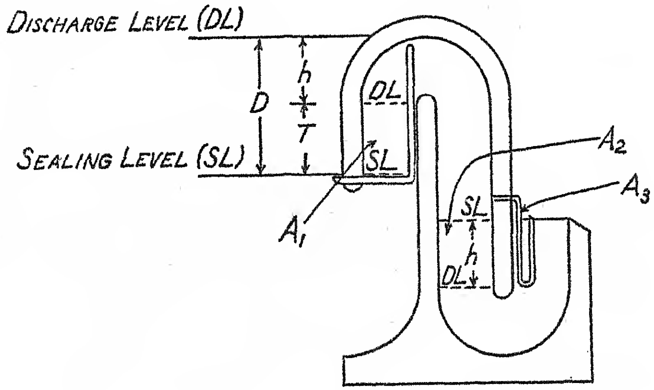

*Courtesy National Malaria Society*

Figure 53. Comparison of Macdonald and Legwen-Howard automatic siphons




*Courtesy National Malaria Society*

Figure 54. Diagrammatic representation of operation of Legwen-Howard automatic siphon




VERTICAL SECTION

$V_1$ = Volume of entrapped air at sealing time.

$P_1$ = Pressure of entrapped air at sealing time = atmosphere pressure.

$V_2$ = Volume of entrapped air at time of discharge.

$P_2$ = Pressure of entrapped air at time of discharge (in lbs./sq. in.).

$A_1, A_2, A_3$ = Cross sectional area of siphon or pipes at designated points.
h = Head of water upon entrapped air, in inches.
T = Depth of water from sealing line to level in upper limb, in inches.

$P_2 = P_1 \div (h \times \frac{.433}{12})$ (wt. of 1 column of water = .433 lbs./sq. in.)

$P_2 = 14.7 \div .036h$

$P_1 V_1 = P_2 V_2 \qquad V_2 = \frac{14.7V_1}{14.7 \div .036h}$

Contraction of air $= V_1 - V_2 = V_1 - \frac{14.7V_1}{14.7 \div .036h} = V_1 - \frac{V_1}{1 \div .0025h}$

$V_3$ = Volume of water displaced by air in lower limb and vent $= h(A_2 \div A_3)$

$V_4$ = Volume of air displaced by water in upper limb $= V_3 \div (V_1 - V_2) = h(A_2 \div A_3) \div (V_1 - V_2)$

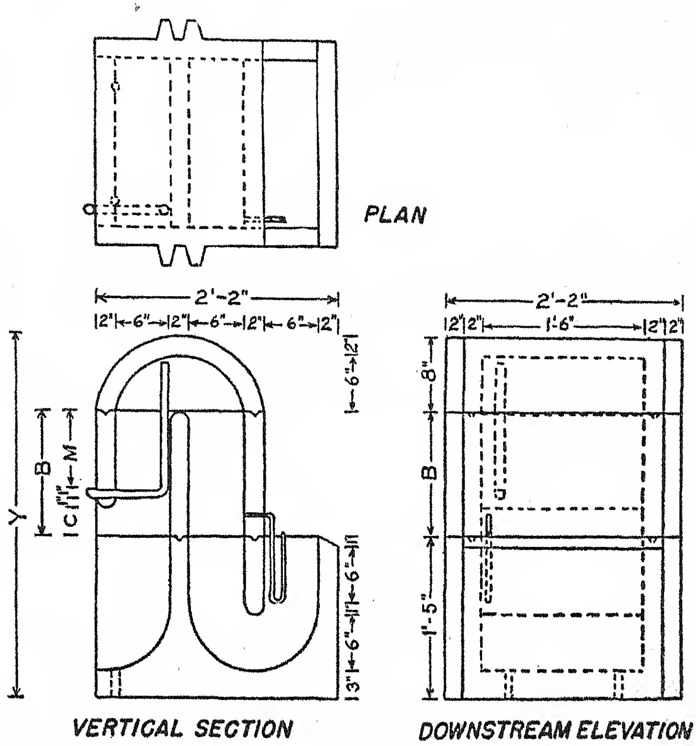
$$T = V_4 \div (A_1) = \frac{h(A_2 \div A_3) \div (V_1 - V_2)}{A_1} = \frac{h(A_2 \div A_3) \div (V_1 - \frac{V_1}{1 \div .0025h})}{A_1}$$

$D = h \div T$

$$D = h \div \frac{h(A_2 \div A_3) \div V_1 - \frac{V_1}{1 \div .0025h}}{A_1}$$

*Courtesy National Malaria Society*

Figure 55. Formulae and computations for use with Legwen-Howard automatic siphons

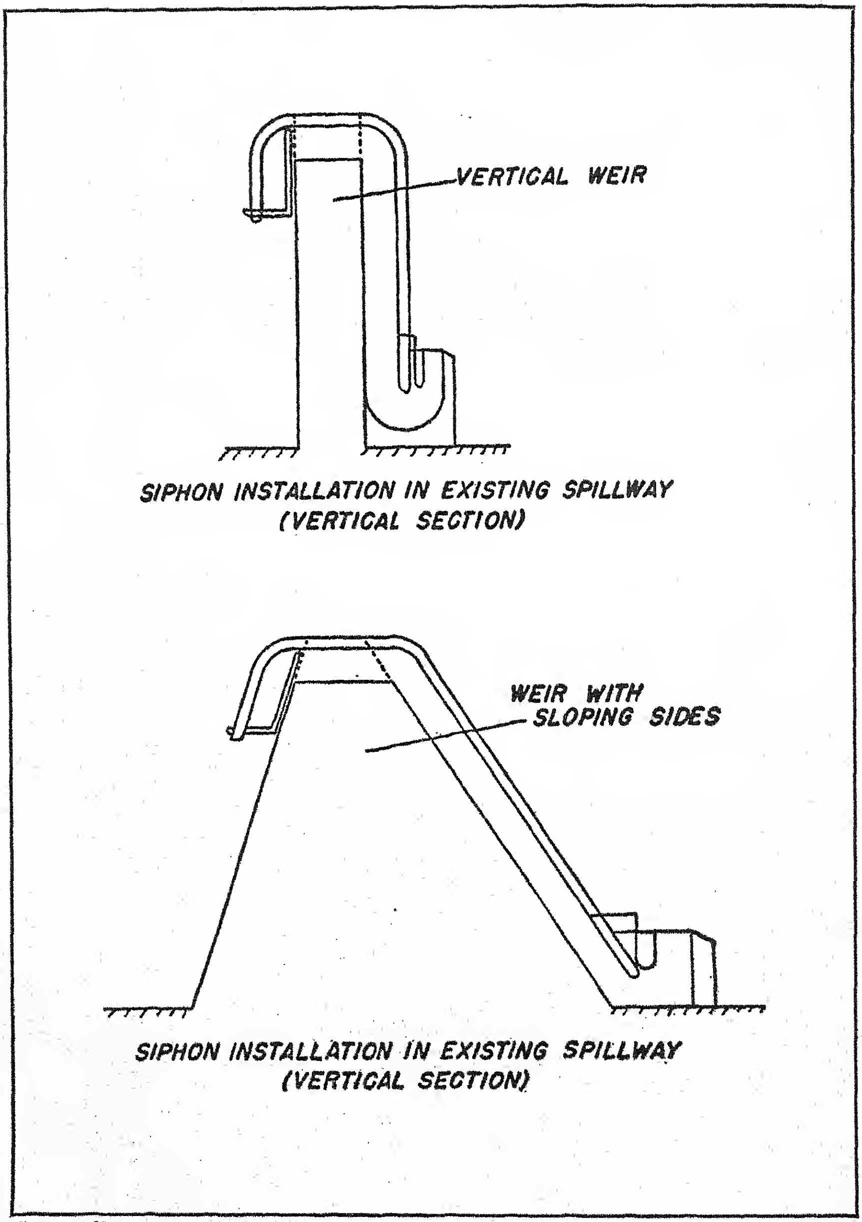



VARIABLE SIPHON DIMENSIONS IN INCHES

| Min. head | Max. head | Fluct. depth | Height Y | B | C | M |
|---|---|---|---|---|---|---|
| 4 | 19½ | 15½ | 38½ | 13½ | 3 | 8½ |
| 12 | 27¾ | 15¾ | 46¾ | 21¾ | 11 | 8¾ |
| 24 | 40 | 16 | 59 | 34 | 23 | 9 |
| 36 | 52¼ | 16¼ | 71¼ | 46¼ | 35 | 9¼ |
| 48 | 64½ | 16½ | 83½ | 58½ | 47 | 9½ |

*Courtesy National Malaria Society*

Figure 56. Measurements for several sizes of Legwen-Howard automatic siphons




*Courtesy National Malaria Society*

Figure 57. Methods of installing Legwen-Howard automatic siphons in existing dams or weirs

The increase in discharge rates is apparently about 60 per cent.

Legwen has also (personal communication) modified his siphon to work on a minimum head of as little as one inch, by replacing the regular priming vent with another at a higher elevation connected through the cover of the siphon into the throat. In this manner very small flows can be used to actuate the siphon without leakage or flow-through. He has also used the siphon successfully to fluctuate the water level in small impoundments breeding *Anopheles quadrimaculatus*.

Cochrane and Newbold[9] have used an automatic siphon to control stream-bed breeding of *Anopheles argyritarsus* in Grenada, and appear to have developed improvements in design which reduce entry losses and give a better discharge through the throat of the siphon.

Automatic flushing devices cannot be depended upon to operate continuously and effectively unless they are inspected at reasonably frequent intervals, to see that the priming and sealing vents are clear, that debris is kept away from the inlet opening, and that the equipment is not tampered with by curious or malicious persons.

Besides its use in Malaya, Ceylon, and the Philippine Islands, flushing has been used successfully in the Netherlands East Indies, Bengal, and Palestine, and it is being extended to new areas. The earliest users of this method were apparently J. A. LePrince[10] at Panama and Sir Ronald Ross[11] at Ismalia. LePrince used hand operated gates improvised out of waste materials available from construction work.

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# XI

## OILS AND LARVICIDES

PETROLEUM OILS and appropriate larvicides are essential but definitely auxiliary and emergency means in mosquito control. Their secondary place in a well-conducted abatement project has been predicated in previous chapters and deserves special emphasis in the discussion here, particularly as their usefulness is so often misunderstood or overrated. It is unfortunate that in the minds of so many people mosquito abatement has become synonymous with oiling. It is even more unfortunate that abatement agencies often resort to oils when primary control measures would be not only more effective but in the long run less expensive.

In any use of oils or larvicides the principle should never be forgotten that the primary job of abatement is to eliminate the breeding places of mosquitoes or to reduce the number and extent of their breeding places as far as possible within reasonable cost. The correct use of any oil or larvicide for the destruction of mosquito larvae and pupae is to employ it as an adjunct or supplement to the primary measures for the elimination of mosquito breeding places; as a temporary method pending the installation of primary measures; as an emergency measure following floods or other unusual conditions; as the only available method in a few instances where primary measures such as drainage are not applicable (for example, impounding reservoirs); and in the relatively few cases where the capitalized annual cost of oiling or larviciding is considerably less than the cost of primary control measures.

Within the limitation of the foregoing principles, the use of oils and larvicides should be considered with reference to the suitability, effectiveness, and relative cost of 1) available oils and larvicides (the subject of this chapter), and 2) methods of application (discussed in the following chapter). Consideration of both is essential to sound abatement procedure whenever oiling is necessary. Preoccupation with the problems of the application of oils may result in unjustifiable expense and inadequate abatement when the materials used are not carefully selected.

Four general types of materials have been used to kill mosquito larvae and pupae: 1) oils, petroleum derivatives principally, though some attempt has been made to use various vegetable oils; 2) ingested poisons, for example, Paris green; 3) water-soluble poisons; and 4) emulsions containing toxic substances.

For all these materials our present knowledge is inexact and too purely empirical for a really satisfactory presentation of required information. Little is known as yet either scientifically or practically concerning the exact effects of these various materials upon mosquito larvae and the methods by which they cause death. What facts we possess, though considerable in some phases, are separated, on the one hand, by wide gaps in essential information and, on the other hand, by extensive jungles of surmise, snap judgment, mere beliefs, empiricism, and inadequately analyzed observations. Therefore what we write is to be taken simply as a presentation of the facts as far as they are available to us at the present time, arranged and interpreted in accordance with our best judgment. New information may later materially modify our ideas.

Since supplies of pyrethrum and of petroleum oils have become scarce during the present war, it is necessary to find new larvicidal materials which can take their place effectively and economically. Several such materials are being tried, but adequate information concerning field trials is not yet available in some cases.

## *PETROLEUM OILS*

When L. O. Howard[1] in 1892 published his statement that kerosene would kill mosquito larvae, he not only made available a procedure for the destruction of mosquitoes, but also started a chain of ideas which have failed to receive much critical analysis. Ask any oiler in a mosquito abatement gang how an oil film on water kills mosquito larvae and he will probably answer, "Why, the oil cuts off their air and suffocates them, of course." And yet three simple experiments which this oiler could easily make would show that statement to be either incorrect or at least decidedly doubtful.

Take an ordinary four ounce glass-stopper bottle, fill it completely up into the neck with clean, cold, well-aerated tap water. Place two or three full-grown mosquito larvae in the bottle and insert the glass stopper in such a way that no bubble of air remains under the stopper, so that the larvae cannot obtain any air through their breathing siphons. Put the bottle in a cool, shaded place and observe the larvae at half-hourly intervals. After several hours they will still be alive and if placed in a refrigerator at 40° F. will probably be still alive after twenty-four hours. When removed to an open jar of water, they will proceed to pupate and emerge as normal mosquitoes.

For the next experiment, place several mosquito larvae and pupae in an open jar and pour a little of any light petroleum derivative (gasoline, kerosene, or stove oil) on the water surface. After the larvae have had several contacts of their breathing siphons with the oil film, float off or absorb the oil film and remove the larvae and pupae to a jar of clean water where they have free access to the air. Within an hour the larvae and pupae will be either dead or moribund.

In the last experiment, substitute any highly refined non-volatile petroleum oil such as medicinal mineral oil, proceeding otherwise as in the second experiment. The larvae will probably die after many hours, but the pupae will survive perhaps for days and a few may even succeed in emerging as adults.

These three experiments indicate that deprivation of oxygen (suffocation) will ultimately kill mosquito larvae, but this is a relatively slow and uncertain process; if the rate of metabolism of the larvae is slowed down by low temperatures, they can survive for many hours by utilizing what oxygen is dissolved in the water. The third experiment indicates that deprivation of oxygen through a blocking or plugging of the breathing siphon is probably of minor significance. What kills the larvae would appear to be some quality of an apparently poisonous nature in the lighter oils. Further experiments would soon show that the lighter and more volatile the oil (in general, and with certain limitations to be discussed later), the quicker and more certainly the larvae would be killed.

In order that a reasonable knowledge may be had of the best type of oil to use in mosquito abatement, at least four lines of scientific information are required, which must be evaluated in relation to each other and to the practical objectives. These are: 1) chemical and physical studies of the composition and properties of oils, particularly petroleum and its constituents and derivatives; 2) entomological studies, especially in insect physiology, on the effects of oils, particularly the various petroleum fractions, upon mosquito larvae, and on the method by which death is caused; 3) physicochemical studies of the properties of oil films on water surfaces; 4) analyses of costs.

## CHEMICAL AND PHYSICAL PROPERTIES OF PETROLEUM OILS

Petroleum oils are extremely complex mixtures of various carbon compounds; and crude petroleums vary widely in composition according to the characteristics of the field from which they are derived. The crude petroleum contains many of the members of the saturated hydrocarbons of the aliphatic series, from $CH_4$ (methane or marsh gas) to $C_{27}H_{56}$ and slight amounts of compounds of even higher molecular weight. This series is frequently called the paraffin hydrocarbons. In addition to the paraffin hydrocarbon series, petroleum also contains certain unsaturated, cyclic, and aromatic hydrocarbons and compounds containing nitrogen, oxygen, and sulphur.

Petroleum is frequently classified as an asphalt-base oil if the residue after distillation is rich in asphalt (a black, heavy heterogeneous mixture of polymers of aromatic and aliphatic hydrocarbons and their oxidation products) or as a paraffin-base oil if the residue is relatively rich in the solid hydrocarbons of the methane or paraffin series and relatively low in asphaltic compounds. There may be various gradations between these two general types of crudes.

The variation in oils from different fields is quite marked. Pennsylvania oil is largely composed of compounds of the paraffin series ($C_nH_{2n+2}$) and cyclic compounds; oils from the Texas, Oklahoma, Kansas, and California fields contain various aromatic derivatives in addition to the paraffin series; oils rich in naphthenes and their homologues are found in Russia.

In the commercial preparation of a petroleum product such as gasoline (distillation range 50° C. to 225° C.) the refining process removes most of the higher boiling fractions, including the waxes and asphalts, and also usually most of the benzene derivatives and the unsaturated hydrocarbons, together with the sulphur and nitrogen components. In other commercial grades such as diesel oil and stove oil (excluding refined lubricating oils) intermediate boiling fractions are separated from the low-boiling liquids and gases on the one hand and the higher boiling solids on the other, but such compounds as unsaturated hydrocarbons and benzene derivatives, together with sulphur and nitrogen compounds, may not be removed or may be only partially removed in the refining process. Some of these compounds (which may be considered as impurities) appear to have definite toxic effects upon mosquito larvae over and above the effects of the volatile hydrocarbon fractions.

Owing to the wide variation in the components of crude petroleums, it is not to be expected that oils distilled within the same temperature range but derived from different source fields would have the same effect or value as mosquito larvicides. Variations in the components other than saturated hydrocarbons may make large differences in toxicity, viscosity, spread, stability of oil film, and in cost, within the same boiling points. It is therefore improbable that a specification drawn for mosquito abatement oil derived from Texas crudes could be applied without modification to such oils derived from Arabian crudes. Specifications for mosquito-killing oil, so far as the physical characteristics of boiling range, viscosity, and specific gravity are concerned, must be varied to accord with the characteristics of the crude petroleum available in the area in which mosquito abatement work is to be done. For the same reason, specifications for toxicity and spreading coefficient should also be modified to accord with the characteristics of the available oils.

The chemical and physical properties of an oil will have a marked effect on the stability of an oil film on a water surface. In the presence of certain types of compounds, an oil film may break down rapidly, coalesce into globules, or split up into patches within a short time. Effective oils should have a reasonable film stability, which is a phenomenon to be distinguished from film persistence; a thick coating of non-volatile, non-toxic oil might be persistent, but a thin film thereof might be unstable. Film persistence will be discussed later.

Murray's work,[2] to which further reference will be made, indicates that to assure film stability mosquito abatement oils should have either a very low or a very high aromatic content, but should not contain aromatic compounds in proportions nearly equal to the saturated hydrocarbons, unless they are high boiling point aromatics; the oil should consist of widely overlapping cuts of oils; and should not contain fatty acids or fats, especially if added as spreaders. We have not as yet been able to devise any satisfactory specifications for film stability. Our only method of determining it at present is empirical and consists of spraying samples of the oil in the field and observing the behavior of the oil film over a period of several hours.

Specific gravity, which should be expressed as a direct numerical weight per volume ratio in relation to distilled water but which commercially is frequently expressed in Baumé degrees (for example, 27° B.), has been used in some cases as almost the sole criterion of a mosquito oil. Actually specific gravity is of relatively little importance as a criterion for an oil for mosquito abatement; its principal value in specifications is (in connection with viscosity) to obtain oils which will be readily sprayable at moderate pressures. We have found 0.83 to 0.86 to be a satisfactory range of specific gravity.

Viscosity is the resistance of an oil to flow when a force is imposed upon it, and is measured usually in seconds of time at 100° F. on the Saybolt Universal Viscosimeter which times the efflux of a definite quantity of the fluid through a short tube. Oils of high viscosity (thick, heavy oils) would require considerable power application to force them through spray nozzles and probably would not spread as well as lighter oils of lower viscosity. We have found a range of 31 to 43 Saybolt Universal at 100° F. to be satisfactory for mosquito abatement oil.

### Toxic effect of oil on mosquito larvae

Apparently Howard's observations on the killing of mosquito larvae by kerosene did not begin to receive any critical examination until 1917, when Moore[3] showed that toxicity was associated with volatility and suggested that the structure of insect respiratory organs was probably responsible for the influence of volatility upon the toxicity of volatile organic compounds. Takatsuki,[4] experimenting with both light and heavy oils, showed that the cause of death was not a mechanical suffocation from the stoppage of the breathing pores and found that the surface of the siphons and respiratory organs is covered by an epithelial membrane which has a special affinity for petroleum oils. This membrane is not stained by water solutions of dyes, but is readily stained by petroleum solutions of dyes. He also showed that a thick layer of oil was unnecessary to kill mosquito larvae.

Freeborn and Atsatt,[5] by studying the effect of colored petroleum oils on mosquito larvae, came to the conclusion that the volatile constituents of the oils contained the principles which produced the primary lethal effects: that these effects are produced by the penetration of the volatile fractions (vapors) of the oils into the tracheae of the larvae and pupae; that the toxicity of an oil is in direct proportion to its volatility; and that with heavy, involatile oils (boiling point greater than 250° C.) mechanical suffocation may have some supplementary effect. They also tested various theories as to the effect of oil in killing mosquitoes and found that 1) the idea that oil lowered the surface tension of water so that larvae could not maintain themselves at the surface was incorrect; 2) direct suffocation was of little effect; 3) poisoning of larvae was not caused by toxic substances dissolved from the oil by the water; 4) blocking of the tracheal tubes by oil, as suggested by Ross in 1902, may have some slight effect, but it is secondary; and 5) oil as a contact poison is of little effect as death results before the oil thoroughly penetrates the general tissues.

Hacker[6] showed that a complete film of oil was not necessary in order to kill mosquito larvae, and that a momentary contact with a film of toxic oil was sufficient to cause death, even if the larvae were then transferred to clean water. Green[7] showed that with *Anopheles* larvae very short periods of contact with volatile oils (gasoline twelve seconds, kerosene four minutes) were sufficient to cause death, that increased exposure beyond that point did not hasten death appreciably, and that *Culex* larvae required six to eight times more contact time to kill than *Anopheles*. Hacker[8] found that volatile hydrocarbons condense as a film on the lining of the larval tracheae and produce a pseudo-anaesthetic effect; this film increases the absorption of metabolic end-products (acids and alcohols) which enhance the toxic action to a total true anaesthesia.

Ginsburg[9] tested the penetration of dye-stained oils into the respiratory system of mosquito larvae and pupae and concluded that lighter oils (boiling ranges from 200° F. to 500° F.) killed by a direct toxic effect within thirty minutes or less, and that oils of high boiling ranges (for example, lubricating oils) caused a slower death by suffocation, the rate of killing being somewhat proportional to the thickness of the oil film. The breathing siphons of *Culex* larvae can readily penetrate oil films of the thickness usually applied on mosquito breeding water. He also found that larvae whose respiratory siphons were filled with non-toxic heavy oil did not develop into pupae, but that pupae whose breathing trumpets and even part of the thorax were filled with non-toxic oil could under certain conditions develop into adults.

Corbett and Hodgkin[10] suggested that volatility in itself was not of primary importance, but that toxicity and retention of toxicity over a period of time were the factors to be considered.

A considerable literature on the effect of oils upon mosquito larvae has appeared from 1910 to the present, much of it inadequate, contradictory, or erroneous. Even textbooks have been guilty of entirely wrong statements, for example, "The larvae are suffocated, through inability to penetrate the film with their breathing tubes."[11] The items we have cited appear to us to be the most significant, up to the work of Murray. If the significant papers we have quoted had been heeded by, or even known to, practical mosquito men, there would have been fewer failures and less waste of effort and money. But to many of them oil was oil, and even some of the experts were mere empiricists in this phase of the work.

Murray[12] proceeded to attack anew the problem: how do larvae die under oil treatment? He succeeded in making microscopic studies of the effect of unstained oils on larvae, particularly *Culex*, whose tracheal system is more easily observed. The inner surface of the tracheae is composed of a material, perhaps waxy in character, which is wetted by oil but not by water. Almost any oil or similar organic material causes these membranes to lose their metallic appearance and become transparent, and the presence of any kind of oil *in* the tracheae is ultimately fatal. However, the survival time may vary widely from a few minutes to a week or more, depending on toxicity and various other factors, such as differences in the amount of oil taken into the tracheal system which will vary with the number of times and the length of time the larva contacts the oil film. The number and length of contacts are in general smaller with oils of higher toxicity, and therefore the most toxic oils (toxicity being considered apart from volatility) are not necessarily the best larvicidal oils. With highly volatile oils some larvae may even escape oiling for a considerable length of time, thus outliving larvae which have taken in a fatal quantity of a less volatile oil. Murray found that penetration of the tracheae at ordinary temperatures was accomplished most rapidly by oils of the middle boiling range (200° C. to 300° C.). He also disposed of the fallacy of "lasting" quality of the oil film, showing that the cause of effective mosquito control is not served by depending on long persistence of oil films in the presence of recurrent breeding.

G. I. Watson[13] has made significant studies, only partially published, on the manner in which oils kill mosquito larvae, and has developed useful techniques for observing the effects. He shows that toxic oils entering the tracheal system may kill by paralysis of the skeletal muscles of larvae. In addition, some toxic oils kill microscopic organisms which are food for larvae, and in the case of surface feeders this may result in starvation. He also showed that if enough heavy fractions of oil enter the trachea, they may prevent molting or cause suffocation. With surface-feeding larvae, also, the heavy fraction of an oil may so mat the mouth-brushes as to prevent feeding and cause death by starvation. Watson also emphasizes the need for toxicity and good spreading qualities in an effective larvicidal oil.

### Testing oils for toxicity

Except for an understanding of the lethal effects upon larvae and their reaction to various types of oil, it is not necessary in testing oils for toxicity to distinguish between the effects of volatile saturated hydrocarbons and the toxic properties of unsaturated, cyclic or aromatic hydrocarbon components of the oil. Two practical methods of testing are:

1. The most logical test: put say ten larvae and five pupae in a tall glass cylinder not over two inches in diameter, filled with clean water practically to the top. Insert a glass tube to the bottom of the cylinder and connect it by rubber tubing to a source of water supply. Adjacent to the cylinder, place several glass containers filled with clean water, and a glass tube with a rubber suction bulb on one end. Timing the operation, with a stop-watch if available, put a film of the oil to be tested onto the water surface in the cylinder containing the larvae, with as little disturbance as possible. After thirty seconds, provided all larvae and pupae have been in contact with the oil, introduce fresh water gently by the glass tube to float off the oil, finally absorb the oil with blotting paper or similar material, and transfer the larvae and pupae by means of the glass tube with suction bulb to the jar of clean water. They should then be kept under observation to determine the time of death. Repeat the experiment, increasing the time of contact by half-minute increments up to a total contact time of five minutes. If an oil will not kill within a total contact time of five minutes, it is probably either insufficiently toxic or insufficiently volatile to be of use for mosquito abatement. (Contact time should not be confused with the elapsed time from contact to death. Reasonably toxic oils will kill within one hour of elapsed time after initial contact with the oil film.)

2. A simpler test, satisfactory for most purposes: put say ten larvae and five pupae in ordinary one-pint glass jars half filled with water, and apply a thin surface film of the oil to be tested. Record the time elapsed until all larvae and pupae are dead.

Death may be defined as the state when all movement has ceased and the larvae or pupae fail to respond by reflex muscular movement to sharp taps with a lead pencil on the side of the jar. The shorter the period of contact which produces death in the first method, or the shorter the elapsed time to produce death in the second method, the more effectively toxic, probably, is the oil tested.

Murray[12] has shown that with oils of extreme volatility or toxicity the irritative effect on the larvae may be so great as to prevent an intake of oil into the tracheal system for some time, and so delay effective killing, or even under natural conditions possibly may permit an escape of some larvae from contact with the oil. Extreme toxicity or volatility is therefore probably not desirable in a larvicidal oil.

As an illustration of the variation in toxicity of different oils, Table 6 shows results we obtained, using test No. 2 with *Culex tarsalis* larvae and pupae against oil samples submitted on a call for bids.

TABLE 6. Toxicity of oils for larvae

| | KILLING TIME IN MINUTES | | | |
|---|---|---|---|---|
| | Trial A | Trial B | Trial C | Average |
| Stove Oil 34°B. | 46 | 40 | 40 | 42 |
| Stove Oil 32°B. | 43 | 38 | 47 | 43 |
| Kerosene No. 1 | 58 | 39 | 43 | 47 |
| Stove Oil No. 4 | 50 | 44 | 50 | 48 |
| Kerosene No. 2 | 61 | 40 | 53 | 51 |
| Stove Oil No. 5 | 61 | 53 | 50 | 55 |
| Kerosene No. 3 | 69 | 46 | 55 | 57 |
| Stove Oil 27°B. | 77 | 43 | 64 | 61 |
| Kerosene No. 4 | 78 | 59 | 62 | 66 |

It will be noted that all the stove oils had higher boiling ranges than the kerosene, but that the two lightest stove oils killed more quickly than any kerosene. The most effective kerosene was apparently the least refined, judging from the odor and price. The two highly refined kerosenes were about as slow in killing action as the 27° B. stove oil.

Another simple experiment, which is rather enlightening, is to place several larvae and pupae in each of four jars of clean water, and apply thin films of the following materials, one to a jar:

1. High grade smokeless kerosene
2. A diesel oil or stove oil
3. Kerosene to which has been added five per cent of cresylic acid
4. Pyrethrum extract (fly spray) in kerosene solvent

Observe the bottles for a period of about fifteen minutes, and thereafter at ten-minute intervals. The larvae in bottles 3 and 4 will probably be dead within fifteen minutes; in bottle 2 they will probably be dead within forty minutes; but the larvae in bottle 1 will probably survive for about an hour. As the volatility of the kerosene in bottles 1, 3, and 4 is the same, the greater rapidity with which death occurs in 3 and 4 must be attributed to the toxic effects of cresylic acid and pyrethrum, and similar reasoning would indicate that toxic impurities in the less refined oil in bottle 2 probably also accelerated death.

### Precautions regarding toxicity

Any oil used in mosquito control should be non-toxic to stock (cattle, horses, etc.), wild life, and aquatic life, especially fish. To safeguard crops it should also be non-toxic to vegetation, but when crops do not need to be considered a high toxicity to vegetation is a decided asset in killing off growths that protect mosquito larvae from contact with oil.

In our experience, moderately toxic and volatile oils, applied adequately but in the minimum amounts to satisfy effectiveness and economy, do not have any deleterious effects upon fish, water birds, or aquatic life in general. On the other hand, heavy oils ignorantly applied in excessive quantities are undoubtedly deleterious in their effects. Such bungling inefficiency should be condemned by mosquito abatement agencies as well as by the conservationists.

Some types of oils may be toxic to the workmen applying them because of excessive quantities of phenolic or similar substances in the oil, or may be offensive to use because of unpleasant odors. Some materials we have experimented with have had to be abandoned, though otherwise excellent, because of the severely irritating effects on mucous membranes (eyes, nose, and mouth); others had persistent, pervasive odors which built up to a nauseating effect. In the effort to protect themselves, workmen cannot or will not use such materials efficiently and they should not be expected to use them.

SPREADING PROPERTIES OF OIL ON WATER SURFACES

The formation and characteristics of oil film on water surfaces have been investigated by many scientists, among whom may be particularly mentioned Rayleigh, Langmuir, and Rideal. Surface phenomena, particularly where petroleum oils are involved, are extremely complex and highly technical, and the literature on the subject is voluminous. From a practical standpoint, the recent work of Murray[2] and that of Gray and Bent[14] are the most immediately useful.

The tendency of an oil to spread or not to spread on a water surface is determined by the three surface tensions existing when a small quantity of oil is placed upon a relatively large water surface. These surface tensions are

1. The water-air surface tension, $S_w$
2. The oil-air surface tension, $S_o$
3. The oil-water surface tension, $S_{ow}$

These surface tensions are forces acting parallel to the three surfaces of contact between water and air, oil and air, and water and oil, respectively. Expressed in terms of dynes per centimeter (dynes/cm.) they are the force components of the work necessary to overcome the cohesive forces of the liquid when one square centimeter of new liquid surface is made.

The spreading coefficient, a measure of the capacity of an oil to spread on a water surface, is expressed by the formula:[15]

$$\text{Spreading Coefficient} = S_w - (S_o + S_{ow})$$

An examination of this equation shows that an oil will tend to spread only when the water-air surface tension exceeds the sum of the oil-air and oil-water surface tensions, and that the smaller the sum of the oil-air and oil-water surface tensions in relation to the water-air surface tension, the greater will be the spread. It is also seen that anything which will reduce the water-air surface tension (such as certain dissolved or colloidal substances in water) will also reduce the spreading coefficient of the oil.

The surface tension of pure water (72 dynes/cm. at 25° C.) is generally higher than the sum of the other two surface tensions, and as a result most oils tend to spread on a water surface. However, water encountered in mosquito abatement work is not pure; it contains a wide variety of dissolved or colloidal substances. Such materials as fatty acids and their salts (soaps) and organic matter (such as sewage and vegetable extracts) are highly surface active, and lower the surface tension of water to a figure that is sometimes not enough to spread the oil. This phenomenon has been observed on many occasions by mosquito abatement workers, especially on peaty marshes and on marshes heavily polluted by sewage. On the other hand, certain dissolved salts, such as some chlorides, increase the water surface tension and increase the spreading capacity of oil.

The surface tensions of oils vary somewhat according to their composition. For the petroleum derivatives, their range is from 23 dynes/cm., for low-boiling fractions such as gasoline, to about 30 dynes/cm., for high-boiling fractions such as diesel oils. Other factors being equal, the oils of lower boiling range may have better spreading power than oils of higher boiling range.

The interfacial tension of the oil-water interface is subject to extreme variation. Murray[2] found that the usual range of the normal products and by-products of petroleum refineries either had no spread (kerosenes or white neutral oils) or had spreading coefficients of from 8 to 20 dynes/cm. The special malaria oil used in India had a spreading coefficient of about 25 dynes/cm. In general the more highly purified the petroleum derivative, the higher will be the value of the oil-water interfacial tension, and therefore the lower will be the spreading coefficient. For example, the oil-water interfacial tension of a highly refined smokeless kerosene is about 50 dynes/cm., at 25° C., while that of a cheaper, less highly refined grade of kerosene is about 45 dynes/cm. Their oil-air surface tensions are approximately the same at 26 dynes/cm. The spreading coefficients are therefore respectively −4 dynes/cm., and +1 dyne/cm., showing that the more highly refined kerosenes will not spread at all and the less refined kerosenes will spread but little. This fact has been frequently observed in practical field trials and can be experimentally confirmed by placing a drop of each type of oil on a water surface.

The contrast is more pronounced between smokeless kerosene and a light stove oil having an interfacial tension of 33 dynes/cm. and a spreading coefficient of 12 dynes/cm.; or between smokeless kerosene and a light diesel oil having an interfacial tension of 23 dynes/cm. and a spreading coefficient of 20 dynes/cm. The heavier diesel oil is seen to have a better spreading coefficient than the lighter stove oil or the still lighter kerosene (the specific gravities being respectively about 0.85, 0.84, and 0.80). The enhancement of spreading power, running contrary to specific gravity and boiling range, is attributable to an increasing amount of certain impurities which are not removed in the refining process. These impurities are principally aromatic petroleum components, unsaturated compounds, and polar compounds such as organic acids or alcohols, which orient themselves at the interface and consequently lower the interfacial tension.[15]

These observations give clues to possible developments along the line of improving the spreading properties of petroleum oils for mosquito abatement, either by a straight-run refining process to produce an oil of the most favorable characteristics for this work, or by the addition of aromatic, unsaturated or polar components to a low-cost oil to increase spreading capacity and toxicity. Murray's work,[2] the second part of which was not available when much of our work on this problem was performed, indicates that cracked spirit gum and some of the products of sulphonation of petroleum are useful additions to oils for increase of spread, but that the addition of phenols and higher alcohols is based on a fallacy, as the water-soluble components of such materials escape from the oil into solution in the water, thus causing a break-up of the oil film.

Table 7 from Gray and Bent[14] illustrates the ranges of surface tension and spreading coefficient for various petroleum derivatives.

TABLE 7. Spreading coefficients of oils

| Oil | Surface tension dynes/cm. | Interfacial tension dynes/cm. | Spreading coefficient |
|---|---|---|---|
| Neutral white oil | 31.3 | 56.6 | −15.9 |
| High grade kerosene | 26.1 | 50.5 | −4.6 |
| Cheap grade kerosene | 26.5 | 45.0 | 0.5 |
| Light stove oil | 27.3 | 32.9 | 11.8 |
| High aromatic kerosene extract | 30.5 | 22.9 | 18.6 |
| Diesel oil | 29.2 | 23.1 | 19.7 |
| Special mosquito oil | 29.4 | 15.0 | 27.6 |

(Boiled distilled water has a surface tension of 72.0 dynes/cm. at 25° C.) The kerosene extract shown in the table was the impurities-containing residue obtained on the final refining of kerosene. As a by-product it might be obtainable in some areas at a sufficiently low price to be economical, especially as a base for a compounded larvicidal oil. The special mosquito oil was a diesel oil especially treated by additional substances to increase the spreading coefficient.

In June, 1939, we ran some spraying tests with a specially treated oil having a reported spreading coefficient of 34. This oil covered the water surface at the rate of 3.8 gallons per acre; it had a toxicity to mosquito larvae about equal to that of diesel oil. The oil film, while apparently stable, was in our opinion too thin for practical field work.

It is interesting to note that the spreading coefficient of an oil decreases with an increase in temperature. For example, diesel oil which had a spreading coefficient of 19.6 at 25° C. was found to have a coefficient of 24.5 at 3° C., and 19.0 at 50° C. Generally we have thought that oils spread better on water in warm weather than in cold weather, but on the basis of field experiments with several types of oil, in which the area covered corresponded quantitatively with the spreading coefficients, we are now inclined to believe that our impressions on temperature effect may be wrong. It may be that spreading coefficient is not the sole criterion of spread under practical application of oils on water.

Ginsburg[16] studied various materials with reference to their effect on the spreading capacity of oils. He found that chemicals with hydroxyl (OH) ions, such as phenols, cresols, and xylenols, were most effective in increasing oil spread. For example, the addition of one per cent of crude cresol (ninety-five per cent cresylic acid crystals) increased the spreading of oil one and one-half times, and also increased the duration of the film.

We have frequently added a cresylic acid larvicide to stove oil and diesel oil, primarily to increase toxicity, and have noticed a temporary increase in spread, associated with a lessened stability of the oil film. Since such additions increase the cost of the oil, they must be evaluated in relation to increased spread and toxicity, on the basis of cost as applied to mosquito breeding areas.

Fellton[17] has devised a number of simple tests for oils, among them being an approximate test for spreading coefficient. Castor oil, which has a spreading coefficient of from 16 to 20 dynes/cm., can be used as a rough standard.

Set upright in a ring stand a clean glass funnel (six to eight inches top diameter), connect the stem with a rubber tube, and clamp to a water faucet. Introduce water and allow it to overflow for a few moments until a clean water surface is obtained, then turn off the water, clamp the tube, and remove a little water from the funnel by slight tilting, so that the surface is about one-eighth inch lower than the rim. Then take two clean glass rods, one in each hand; dip one into castor oil and one into the oil being tested. Carefully place one drop of each oil simultaneously on the water surface in the funnel, placing them near the periphery but at diametrically opposite points. Observe the spread of each drop of oil by looking nearly horizontally along the water surface.

If both oils cover nearly equal areas of water surface, their spreading coefficients are nearly the same. If the castor oil spreads over a larger area than the tested oil, such oil has a spreading coefficient less than about 16 to 20 dynes/cm.; if the difference is great, the oil is unsatisfactory in spreading quality. If, however, the tested oil occupies more area of water surface than the castor oil, it has a spreading coefficient greater than 16 to 20, and its spreading quality is satisfactory.

Fellton has also devised simple tests for toxicity, viscosity, and specific gravity of oils, and a simple test for toxicity of Paris green.

### Cost analysis of oils

The physical and toxic characteristics of a larvicidal oil will in themselves have a marked effect on the cost of oil as applied to water for the purpose of killing larvae. Failure to analyze these costs carefully is probably responsible for some of the decided variations in practice which can be observed, as well as for a marked lack of both effectiveness and economy in the application of oil in some regions.

Analyses of the cost of marsh oiling done by hand sprayers, under our direction, indicate that the following approximate unit costs are reasonably representative:

| | |
|---|---|
| Labor cost per gallon | $0.18 |
| Transportation cost per gallon | 0.023 |
| Equipment charges, supervision, and miscellaneous materials per gallon (administrative overhead not included) | 0.059 |

For purposes of comparison, we have measured the area covered by one gallon of each of three types of oil, efficiently applied by experienced men on practically identical water surfaces under comparable conditions; and have checked the results by duplicate operations. The three types of oil were

1. A specially treated diesel oil with a very high spreading coefficient (S.C. 27). Requires six gallons per acre of water surface for complete coverage with a uniform, stable oil film. Delivered price $0.074 per gallon.

2. Diesel oil (Pacific Specification No. 200) with a spreading coefficient of 19. Requires nine gallons per acre of water surface for complete coverage with a uniform, stable oil film. Delivered price $0.05 per gallon.

3. A lubricating oil (S.A.E. 40) with 6 per cent by volume of gasoline, made up to approximate the characteristics of waste crank case oil. Spreading coefficient not determined but probably negative. Requires at least twenty-one gallons per acre of water surface for at best an uneven, uncertain coverage with poor stability of oil film. Price assumed to be $0.02 per gallon for crude material delivered, as this price is reported to have been obtained in some localities.

The approximate cost of application of each of these oils, per acre of water surface, using the foregoing figures, is as follows:

1. *Cost Analysis for Special Oil*

| | | |
|---|---|---|
| Oil | 6 x 0.074 | $0.45 |
| Labor | 6 x 0.18 | 1.08 |
| Transportation | 6 x 0.023 | 0.14 |
| Equipment, etc. | 6 x 0.059 | 0.35 |
| Total cost | | $2.02 |

2. *Cost Analysis for Diesel Oil*

| | | |
|---|---|---|
| Oil | 9 x 0.05 | $0.45 |
| Labor | 9 x 0.18 | 1.62 |
| Transportation | 9 x 0.023 | 0.21 |
| Equipment, etc. | 9 x 0.059 | 0.53 |
| Total cost | | $2.81 |

3. *Cost Analysis for Waste Lubricating Oil*

| | | |
|---|---|---|
| Oil | 21 x 0.02 | $0.42 |
| Labor | 21 x 0.18 x 1.25* | 4.72 |
| Transportation | 21 x 0.23 | 0.48 |
| Equipment, etc. | 21 x 0.059 | 1.24 |
| Total cost | | $6.86 |

* Because of the greater pressure required in spraying this oil, labor time for spraying was materially increased, hence the approximate factor of 1.25.

It is probable that in all-around work the cost comparison might not prove to be quite so favorable to the first oil, since in "spot oiling" as compared with "sheet oiling" more nearly equal quantities of the first two oils might be used. But considerable vegetation or contaminated water might make the comparison more favorable to the first oil. The unfavorable comparison of the waste lubricating oil with the diesel oil is not exaggerated, and under many circumstances the comparative cost of the waste oil might be more unfavorable, particularly in the presence of much vegetation. If waste crank case oil cost nothing delivered to the sprayer, it would still be excessively costly as applied to mosquito breeding water.

In practice, larger quantities of oil than indicated will be required, 1) because of the absorptive effects of vegetation and soil and of floatage, 2) because of organic contaminants of swamp or marsh water which reduce the spreading property of an oil, and 3) because of a certain amount of wastage which cannot be entirely eliminated. But no matter what the variations in physical conditions of the area sprayed with oil, those oils of greater spreading properties and higher toxicity will in general be more effective; the quantities of oil applied will be roughly in inverse ratio to the spreading coefficient; and the total cost of application, properly analyzed, will be found to be at least roughly parallel to the cost analyses given.

We cannot emphasize too strongly the fact that the price of oil has no necessary relation to the cost of oiling. In our experience, the cost of oil is roughly from fifteen to twenty per cent of the cost of oiling, when efficient oils are used; but as we have shown, the wrong kind of oil, even if obtained free of cost, may still be excessively costly and comparatively ineffective for mosquito abatement.

The methods of cost analysis here suggested are equally applicable to the various larvicidal materials used in place of oil. We have a certain scepticism regarding the actual and comparative economy of some larvicides, particularly pyrethrum larvicide, and to some extent Paris green, as they are reported as a rule only on the basis of price of the material, not on the basis of total cost as applied. For the same reason, we question the economy of the use of bunker fuel oil, as practiced in the Panama Canal Zone.[18] However, a crude oil is occasionally available which has fairly good characteristics and can be obtained at a relatively low price, and applied at a low overall cost.[19]

WASTE OILS

Many persons have had the idea that waste oils, such as waste crank case oil, could be used for mosquito abatement. Such waste oils can usually be obtained for nothing more than the cost of collection. However, these oils are far from uniform in characteristics, are low in toxicity, and usually have much grit or muck which clogs spray nozzles.

Waste crank case oils should be strained to remove grit and should be settled for several weeks to remove heavy residues. The remainder usually must be "cut" or thinned by some lighter petroleum oil, in order to give it good spreading characteristics and to increase its volatile fraction.

Given a heavy oil and a light oil, a simple method of calculating the proportions of each to produce a mixture of predetermined Baumé gravity is as follows:

1. Express the specific gravity of both oils, and of the desired mixture, in Baumé degrees.
2. Write the gravities of each oil, one below the other, on the left side of a square at the corners.
3. Write the desired gravity of the mixture at the intersection of the diagonals of the square.
4. Subtract the gravities on the diagonals from each other and place the differences at the opposite ends of the diagonals, at the right hand corners of the square. These differences are proportional parts of the two oils which are to be mixed.

Example: Given a waste crank case oil of 21° B. gravity and a distillate of 46° B. gravity, to obtain a mixture of 30° B. gravity mix sixteen parts of the crank case oil with nine parts of the distillate.

The use of waste crank case oil implies certain storage and collecting equipment. The oil is collected from scattered garages and filling stations at a fairly uniform rate through the year, but its use is generally confined to a period of about eight or nine months in the year. The use of crank case oil therefore requires collection equipment to gather the material, and storage tanks in which to accumulate a surplus during the winter months and to blend the required mixture.

Shelby County, Tennessee, has been using waste crank case oil for several years with apparent satisfaction at a reported cost of less than two cents per gallon.[20] The Bergen County (New Jersey) Mosquito Extermination Commission has also used waste crank case oil for several years,[21] and has erected two 4500 gallon tanks for its storage.

In view of the newer larvicidal materials now available and the present knowledge of efficient oils, we cannot consider the use of waste crank case oils to be advantageous except in emergencies when better materials are not available.

## Specifications for oils

In preparing specifications for oil it may be desirable, in order to assure reasonable uniformity of the product, to set up fairly narrow limits of range for specific gravity and viscosity, and to control the volatility by specifying a definite table of distillation temperatures and percentage volume recoveries at such temperatures. Such specifications should be set up only after considerable experience with locally available oils and after consultation with the chemists of the oil companies.

Specifications should not contain trade names or grade names for oils, even if a particular oil sold under a trade or grade name, such as diesel, stove distillate, kerosene extract, or the like, is exactly the oil wanted. Commercial agreements, not always publicly announced, between the oil companies frequently require a standard price for certain grades in certain trade areas, thus eliminating competitive prices. In specifying oil by physical properties a better competitive situation for the mosquito abatement agency, and probably better prices, will be obtained if the principal stress is placed on spreading coefficient, toxicity, and film stability and if reasonable latitude is given for specific gravity, viscosity, and boiling range.

We have previously indicated that specifications for oil for mosquito abatement must take into consideration the variations in the characteristics of the crude oil sources in the area in which work is to be done. With this caution emphasized, we present the following oil specifications which we believe will be found satisfactory under a wide range of conditions. It should be noticed that the principal criteria are toxicity to mosquito larvae and spreading capacity.

Oil furnished shall be homogeneous and shall not separate into fractions of different densities on prolonged standing, nor shall it deposit any solid or semisolid material on prolonged standing. It shall be free from granular, flocculent, fibrous, or other material which might cause clogging of spray nozzles. It shall not be subject to change or deterioration by oxidation or otherwise on prolonged standing in tanks or containers.

The oil furnished shall kill all the pupae and full-grown larvae of mosquitoes (*Culex pipiens* or *Aedes dorsalis*) in not to exceed one hour's time during which the oil is applied as a continuous film on clear water of normal dissolved oxygen content containing such pupae and larvae. Such test shall be made in a one quart glass mason jar containing ten larvae and five pupae immersed in one pint of water, uncovered and exposed in full sunlight. The killing time shall be determined by the time after application of the oil (or oil mixture) when all larvae and pupae fail to respond by reflex muscular contractions or other activity to successive sharp blows struck on the side of the container by an ordinary lead pencil.

The oil furnished shall be a product resulting from the distillation or processing of crude petroleum, and shall have physical characteristics lying within the following maximum and minimum allowances:

| | |
|---|---|
| Specific gravity (A.P.I.)* | 27–38 |
| Viscosity<br>Saybolt Universal at 100° F.<br>A.S.T.M.† D 88–36 | 31–43 |
| Initial boiling point<br>A.S.T.M. D 158–28 | 165°–230° C. |
| Final boiling point<br>A.S.T.M. D 158–28 | Max. 800° F. |
| Spreading coefficient | Min. 17.0 |

* American Petroleum Institute.

† The American Society for Testing Materials designates standard methods for testing materials and publishes standard specifications for engineering materials, which are designated by serial numbers indicating the year of adoption by the last group of figures.

The spreading coefficient is hereby defined to be the surface tension, in air, of distilled water, less the sum of the oil-air surface tension of the oil or oil mixture plus the oil-water (or oil mixture–water) interfacial tension, all measured in dynes per centimeter at 25° C., by means of a duNoy tensiometer.

Proposals to furnish oil shall be accompanied by a fifteen-gallon sample thereof. Samples of oil or oil mixture shall be accompanied by a statement giving the physical characteristics thereof, including the spreading coefficient. Field tests of oil will include spreading ability upon various types of water surfaces, spraying characteristics, continuity and stability of film, toxic effects upon workmen, animals, and vegetation, and toxic effects upon mosquito larvae.

Ginsburg[22] suggests the following physical characteristics for a satisfactory larvicidal oil:

| | |
|---|---|
| Type of oil | Distillate fuel |
| Gravity (A.P.I.) | 27–33 |
| Flash | 130° F. or higher |
| Viscosity S.U. (a) 100° F. | 35–40 |
| Odor | Non-offensive |
| Distillation | 10%: 430°–450° F. |
| | 50%: 510°–550° F. |
| | 90%: 630° F. or higher |

BOTTOM OILS

Sammis[23] and others have experimented with oils of higher specific gravity than water, which sink to the bottom and are apparently effective against bottom-feeding larvae. He reports that pools treated with these heavy oils have remained free from larvae for considerable periods.

In a personal communication dated December 8, 1943, Sammis states that heavy or (S/V) bottom oil should preferably be emulsified with Gardinol or some other emulsifier before spraying. A fairly stable emulsion is obtained, which is diluted one to ten for spraying. On contact with the water surface of the area sprayed, the emulsion first spreads, and then the oil begins to sink slowly to the bottom in the form of droplets. The oil is reported by Sammis to kill larvae by ingestion and by contact, and he states that C. W. Williamson in Suffolk County, New York, has obtained a satisfactory kill on pupae. Sammis reports some irregularity in the effectiveness of this oil, many of the tests being very effective and others less effective.

With a 1:20,000 dilution he obtained a 100 per cent kill in one and one-half hours, which was as rapid and effective as a parallel test using the New Jersey pyrethrum larvicide. At a 1:50,000 dilution, a 75 per cent kill on larvae was obtained in one and one-half hours, and a 100 per cent kill in nineteen hours.

The oil had a somewhat toxic effect upon fish, and on vegetation it was destructive to about the same degree as fuel oil.

The present price of S/V culicide oil is stated to be 25 cents per gallon, and per spray gallon Sammis reports the cost to be $0.0275.

## *OTHER LARVICIDES*

There are many conditions under which oils are either ineffective or unsuitable, or other materials are more effective or less expensive. Numerous investigations have been made of various substances which are toxic to mosquito larvae, for the purpose of finding something better and more economical than oil, or something that will be useful where oil cannot be successfully used. On account of excessive cost or other limitations, most of such materials have been eliminated by practical experience. The materials discussed in the following sections are those which so far have been found to be practically useful, and one material which has great apparent possible usefulness, though not adequately tested as yet under a wide variety of conditions.

### Cresylic acid

Crude cresylic acid has several boiling fractions, just as has petroleum oil. In the case of petroleum oil, it is the low boiling fractions that are most toxic to mosquito larvae; but with crude cresylic acid it is the higher boiling point fractions that are the most toxic. We have found that the fraction distilling below 195° C. is but slightly toxic to mosquito larvae and pupae in any reasonable concentrations, whereas the fraction distilling between 225° and 250° C. is toxic to both larvae and pupae in dilutions as high as one to 40,000. The high boiling fraction should be obtainable at low cost from concerns manufacturing *Liquor cresolis comp. U.S.P.*, the refined cresol which is the base thereof being the fraction distilling between 195° C. and 205° C.

For use as a larvicide, the cresylic acid (high boiling fraction) must be emulsified in some way so as to be miscible in water. Various soaps and spreaders may be used for this purpose. The original *Panama* larvicide was made with a rosin soap as the emulsifying agent: 200 pounds of powdered rosin with 30 pounds of caustic soda were added to 150 gallons of crude carbolic (cresylic) acid, with heat and stirring.

The manufacture of such a material requires mechanically stirred vats and distillation apparatus, and is best performed by manufacturing chemists who have the equipment. In 1939 the material in 150 gallon lots on the Pacific coast cost about forty-five cents per gallon packaged in fifty-five gallon drums. The following are general specifications for its manufacture:

The base of the larvicide shall be that fraction of crude cresylic acid which does not distill below 225° C., with which is thoroughly incorporated a suitable soap or spreader (*kind of soap or spreader may be specified if desired*). The mixture shall be homogeneous, shall not separate upon prolonged standing, and shall be free from grit, fibrous, or gummy particles. It shall be freely fluid at all normal temperatures, and miscible in water and in kerosene in all proportions. When diluted with water in the proportion of one part of larvicide to 100 parts or more of water, the emulsion shall be stable for a period of at least thirty days. When diluted in the proportion of one part of larvicide to 30,000 parts of water, said dilution shall be 100 per cent effective in killing the larvae and pupae of mosquitoes (*Culex* or *Anopheles* species) immersed therein, within a period of two hours.

In addition to its use as a larvicide by itself, we have found this material to be a valuable addition to oil in cases where a quick kill (practically with one contact) is necessary, such as under very windy conditions. We also have found that it increases somewhat the rapidity of spread of the oil film, but decreases film stability slightly.

We have found cresylic acid larvicide to be more effective than any oil for control of tree-hole mosquitoes (*Aedes varipalpus*), and on logical grounds believe that it should be effective against *Mansonia* mosquitoes (for example, *Mansonia perturbans*) the larvae of which attach themselves to aquatic plants and seldom come to the water surface.

### Pyrethrum extracts and emulsions

Pyrethrum is the dried flowers of *Chrysanthemum cineraraefolium.* Its essential principle is termed pyrethrin, which is very toxic to many forms of insect life, especially mosquitoes in both the larval and adult stages. It has been extensively used as an insecticide.

Prior to the present war, pyrethrum flowers were obtained principally from Japan, Africa, and Dalmatia. At present, with the greater part of the supply cut off, most of the available pyrethrum is allocated to the military forces and little is available except for the most essential civilian uses. Attempts are being made to produce it in accessible regions where low-priced labor is available.

Used in the form of a spray, it is very effective in enclosed spaces against adult mosquitoes, gnats, and flies. Two types of sprays are normally used. One is a petroleum fraction (high-grade kerosene or a cleaning solvent) to which may be added a portion of carbon tetrachloride to reduce the fire hazard.

The other is an aerosol, the pyrethrin being dispersed from a rapidly evaporating liquid such as Freon (dichlorodifluoromethane). By adding refined oil of sesame as an activator, the quantity of pyrethrin can be reduced and effective killing still obtained. The present quantities are approximately as follows:

| | |
|---|---|
| Pyrethrin ........ | 0.8% to 1.0% |
| Oil of sesame ..... | 2.0% to 4.0% |
| Freon ........... | 97.2% to 95.2% |

The Freon-pyrethrin spray is dispensed from steel cylinders via an atomizer nozzle and shut-off valve. As the Freon is a low-boiling-point material, at ordinary temperatures it maintains its pressure until the entire content of the cylinder is discharged. At present these cylinders are available only for military use.

Petroleum-pyrethrin sprays can be either purchased from manufacturers under various trade names or made direct from pyrethrum concentrates. An effective spray can be made by adding one part by volume of Pyrocide 20 to from fourteen to nineteen parts of refined kerosene or cleaner's solvent. If it is advisable to minimize the inflammability of the mixture, use seventeen parts of solvent and two parts of carbon tetrachloride. An essential oil of pleasant odor can be added to mask the petroleum odor, if desired.

Pyrethrum spray in a petroleum solvent can be used advantageously as a larvicide in certain situations. For example, ornamental garden pools in which water plants are grown can be sprayed lightly with pyrethrum extract to kill mosquito larvae, without appreciable damage to the plants. It can also be used to kill mosquito larvae in outdoor swimming pools. Applied at night, it will be gone by morning and will not interfere with the use of the pool. In flowing springs where mosquito larvae occur, it can also be used effectively, killing the larvae and pupae before the film is removed by the overflowing water, and not contaminating the water. A case of this kind came to our attention at Byron Hot Springs, California, where *Culex pipiens* was breeding profusely in flowing sulphur springs. Pyrethrum can also be used in some cases where there is a prejudice against the use of oil. For example, we frequently find mosquito breeding around hothouses used for commercial growing of flowers. The operators object to the use of either oils or cresylic acid larvicides, but do not object to pyrethrum sprays, which they use themselves to combat various pests.

Pyrethrins apparently oxidize in the presence of air and sunlight and should therefore be packaged and stored in light-proof, tightly closed containers. In water suspensions or emulsions, particularly if alkaline, pyrethrins hydrolize rapidly, especially in sunlight, and lose their toxicity. Spraying emulsions of pyrethrum extract must therefore be used on the day they are made or they are ineffective as larvicides. Concentrated emulsions, if kept packaged in light-proof containers, can retain their potency for several weeks.

Apparently Ginsburg[24] was the first person to develop the practical use of an emulsion of pyrethrum as a mosquito larvicide. The purpose of his investigations was to develop a material which would avoid the disadvantages of oil, and also be less expensive than oil. He prepared an emulsion consisting of kerosene extract (one pound of pyrethrum flowers per gallon of petroleum solvent) emulsified with water and soap (sixty-six per cent extract with thirty-four per cent water containing three to five per cent of dry soap). This stock emulsion was diluted one to ten with water for the field spray. Using more than fifty gallons of the dilution per acre he obtained 100 per cent kill on salt marshes.

Ginsburg[25] reported in 1935 on the use of new emulsifiers for pyrethrum extract larvicide. These are sulphated higher alcohols which, according to Ginsburg, produce an emulsion which does not break down in hard water or salt water, and make practically no increase in cost of the emulsion. One of the emulsifiers is sodium lauryl sulphate [$CH_3(CH_2)_{11}OSO_3Na$] which is sold under the trade name of *Gardinol* by Procter and Gamble, and by E. I. Dupont de Nemours & Co. The other is sulphated butyl-diphenyl-phenol sold under the trade name of *Areskei* by the Monsanto Chemical Co. The formula originally given for preparing the pyrethrum emulsion using these spreaders is as follows:

100 gallons pyrethrum extract (100 gallons kerosene containing extractive from 100 pounds flowers—at least nine-tenths per cent pyrethrins)
6 pounds Gardinol W. A. Concentrated
50 gallons water

The emulsifier is first mixed with the water and violently agitated in the mixing tank. Then the pyrethrum extract is run slowly in, with violent agitation, plus jetting the mixture under high pressure back into the mixing tank, until a thick, homogeneous emulsion is obtained. It is then packaged in steel barrels for field use. For spraying, one part of emulsion is mixed with ten parts of water. Care must be taken to keep the diluted spray well mixed by shaking the spray can occasionally or by operating the paddle in the tank of a power sprayer.

R. J. Vanderwerker,[26] superintendent of the Union County (New Jersey) Mosquito Extermination Commission, used (1935) the following modification of the Ginsburg formula:

| | |
|---|---|
| 100 gallons fuel oil at 6½ cents | $ 6.50 |
| 6 gallons pyrethrum extract (15 pounds of flowers per gallon) at $3.50 | 21.00 |
| 8 pounds Gardinol W. A. paste at 27 cents | 2.16 |
| 50 gallons water | |
| Labor and equipment time | 5.40 |
| Total | $35.06 |

Stock larvicide (156 gallons) at 22½ cents per gallon
Spray gallons (diluted 1 to 10) at 2¼ cents per gallon

On this basis, the modified Ginsburg formula costs considerably less than oil, assuming equal killing efficiency, and about the same cost of application.

The formula generally used at present is:

6 gallons of kerosene or light oil (distillate)
1¼ quarts (40 fl. oz. or 1140 cc.) of 2% pyrethrum extract
3 gallons of water
6 ounces of emulsifier (Gardinol W. A. Concentrated, or equivalent; for fresh-water work 24 fl. oz. of 40% liquid soap, or equivalent in dry soap powder, may be substituted)

To prepare the stock emulsion the emulsifier, if water soluble, is added to the water and thoroughly mixed in the tank (power-operated mixing equipment is necessary for satisfactory results). The pyrethrum extract is then mixed with the oil and added slowly to the water with violent agitation plus jetting back into the tank via the high-pressure pump. This is continued until a homogeneous stock emulsion is obtained. Stock emulsion should preferably be made fresh on the morning of the day it is to be used.

Before spraying, the stock emulsion is diluted in the proportion of one part stock to ten parts water. This dilution is then sprayed at the rate of about fifty gallons per acre. If dilution is made from water obtained in the field, the water should be strained to remove particles which may clog the spray nozzles.

Pyrethrum emulsion has received a fairly general acceptance as a mosquito larvicide, particularly on the east coast of the United States. Clarke[27] is quite enthusiastic over his results with pyrethrum emulsion in the Des Plaines Valley Mosquito Abatement District (Illinois). Rees in Utah, after an initial unsatisfactory experience[28] with this material, has recently[29] been using it within Salt Lake City, and in situations where oil would be objected to, but oil is still the principal larvicidal material used in that district.

Our experience with pyrethrum larvicide has been that under California conditions it cannot compete on a cost basis or in effectiveness with available petroleum oils. All the California districts which have used it have reached the same conclusion. However, Robinson[30] at Modesto used large quantities in the first year of work for the East Side Mosquito Abatement District, at considerably greater cost than for oil, as a method of overcoming an initial prejudice by farmers to the use of oil. For this purpose pyrethrum was highly successful, but after the first year the more economical diesel oil has been used almost exclusively. The advantages or disadvantages of pyrethrum larvicide depend so much on local costs and conditions that we suggest that each agency determine for itself the relative merits of this formula as compared with oil, after actual field trials of the material and after taking all costs into consideration.

Mosquito abatement agencies that have either power spraying equipment or power mixing equipment can manufacture their own pyrethrum emulsion, purchasing the pyrethrum concentrate, emulsifier, and oil. Agencies without such equipment can purchase the material ready mixed in concentrated form, ready to dilute for spraying, from insecticide manufacturers. If considerable time may elapse between manufacture of the emulsion concentrate and its use, the pyrethrum concentrate should be kept in a separate container from the emulsion (oil and saponifier) concentrate and not be mixed until the spray is to be used.

For shipment to the South Pacific on Navy contract we devised for a manufacturer an improved method of making and packaging pyrethrum emulsion. Five gallons, less one pint, of a highly concentrated sodium lauryl sulphate and kerosene emulsion are placed in a five-gallon can; one pint of extra strength (30:1) pyrethrum concentrate is placed in a one-pint can. Two five-gallon cans are placed in a wood box, a two-by-two-inch wood strip placed diagonally on top of these cans, the one-pint pyrethrum cans laid flat on either side of the strip, and the top nailed on. When ready to be used, the pyrethrum concentrate is added to the emulsion in the five-gallon can, thoroughly shaken, and then diluted for spraying. By this method the larvicide can be shipped long distances and arrive with its toxicity unimpaired.

Under some conditions it may be advisable to use an anti-oxidant (hydroquinone, pyrogallol, or the like) to retard deterioration of pyrethrum concentrates.

The quantities of diluted (1:10 or more) spray emulsion which will be required for adequate killing of mosquito larvae and pupae appear to vary widely according to conditions in the breeding water, and are influenced also by the size of the oil droplets[31] in the emulsion and the method of application. The material should be sprayed carefully so as to minimize further dilution by keeping it in a relatively thin layer at the water surface. The usual range of quantities appears to be between forty and sixty spray gallons per acre of water surface.

### Emulsifiers

A wide variety of materials are now available as emulsifiers, but the subject of emulsifiers is a complex one, and any person requiring information or assistance concerning them is advised to consult a competent chemist, particularly one with soap manufacturing experience. Various cheap soaps, such as rosin soap or whale oil soap, can be used for emulsions for fresh-water spraying. Various sulphonated oils have been prepared which give more stable emulsions than soaps. In addition, there is a large number of complex organic chemicals which are excellent emulsifiers, especially in hard or brackish waters which promptly break down soap emulsions. Some of these emulsifiers are water soluble (W.S.), and are added to the water; others are oil soluble (O.S.) and are added to the oil in making emulsions.

PARIS GREEN

One of the most successful of all larvicides, when used against surface-feeding mosquito larvae (anophelines), is Paris green [copper aceto-arsenite ($CuHAsO_3 + 2CuC_2H_3O_2$)] applied as a dust to the water surface. This material is especially suitable to aeroplane dusting operations, but may also be dusted by hand or applied by machine blowers. The Paris green is diluted with road dust, hydrated lime, powdered charcoal, powdered talc (soapstone), or other inert finely powdered material. It apparently acts as an internal poison, the particles of Paris green being taken into the digestive tract with food materials.

Paris green can also be used against bottom-feeding species, by adding it to moist sand and scattering this sand in breeding pools. We have found this Paris green and sand mixture to be fairly effective in killing the larvae of *Culex* and *Aedes* species, but mosquito pupae are unaffected since they do not feed. For successful use it should be applied before pupation has occurred.

Griffitts[32] used Paris green diluted with moist sand as a larvicide against bottom-feeding mosquito larvae. Cook[33] used Paris green diluted with ninety-nine parts (by volume) of moist sand, and obtained excellent results in killing *Anopheles* as well as *Culex* and *Aedes* larvae. Apparently the application with moist sand caused sufficient Paris green particles to remain floating on the water surface (having become detached from the sand grains) and to be effective against *Anopheles* larvae as well as against the subsurface feeders. Cook applied the Paris green by hand, using successfully as low as one-fifth pound of Paris green per acre. The sand should be moist enough to make the Paris green stick to it, but not so moist that it will cake and not spread well when hand-cast. Cook found a substantial saving with Paris green as compared with oil.

There are, however, certain limitations to be put upon the foregoing generalizations. Russell and West[34] found that Paris green diluted with finely powdered charcoal would kill most of the larvae of *Culex quinquefasciatus* as well as the larvae of *Anopheles* mosquitoes. This is probably explainable by the fact that some species of mosquitoes which are normally bottom feeders will occasionally, or even frequently, feed at the surface, bending the abdominal segments and rotating the head so as to bring the mouth parts in contact with the water surface while still maintaining the breathing siphon at the water surface. We have noticed this frequently with *Culex pipiens* and occasionally with other *Culex* species. Such species as are normally bottom feeders but may occasionally feed at the surface would be killed at least in part by Paris green dust applied to the water surface.

Paris green is usually mixed with the diluent in varying proportions according to the method of application. For hand scattering, one or two per cent of Paris green is mixed with the diluent; for hand-operated blowers, 5 per cent to 10 per cent; for power-operated blowers, 10 per cent to 15 per cent; for aeroplane dusting, 25 per cent to 50 per cent. (Note: 33.33 per cent is the usual mixture.)

It is probably a wise precaution to do a certain amount of experimenting to find the lowest percentage of Paris green which can be used effectively, and the safe minimum weight of Paris green per acre of water surface. Such experimenting, if done in the laboratory, should be checked by actual field tests.

As to the total quantity of Paris green to be applied, there is some variance of opinion among users. This variance is probably due to differences in character of the areas treated, and sufficient experimenting should be done in all cases to determine the minimum effective dosage for a particular area and method. Cook and Williams[35] found about one pound of Paris green per acre necessary at Quantico Bay, when applied by aeroplane. King and Bradley[36] in Louisiana found one-half pound per acre sufficient with a safe margin. Chalam[37] in India used from one-fourth pound to two pounds per acre on rice fields, and as high as four pounds per acre where the water surface was thickly covered with water hyacinths. Barber and Hayne,[38] as a result of their experiments in 1921, recommended about 0.43 ounce avoirdupois to 1000 square feet, or about 1.17 pounds per acre. Hackett[39] recommends a liter (1250 grams) per 10,000 square meters of water surface, which is equivalent to about 1.35 pounds per acre.

Commercial Paris green is not uniform in its composition and two factors, the percentage of arsenic and the fineness and uniformity of particle size of the material, seem to have a marked effect on its toxicity to mosquito larvae. The percentage of arsenic expressed as $As_2O_3$ should be not less than fifty per cent; apparently higher percentages of arsenic make the Paris green more toxic. Pure Paris green theoretically should contain 56.62 per cent of arsenic as $As_2O_3$. All of the Paris green should pass a 200-mesh-per-inch screen; and the product is to be preferred which will leave a relatively small amount that does not pass through a bolting cloth of 350 meshes per inch. Apparently Paris greens which have a deep green color are more toxic than those of a paler or duller green color.

There are now being marketed Paris greens specially prepared for use as mosquito larvicides. Manufacturers' claims should be subjected to practical field tests, and the various Paris greens available in any locality should be subjected to controlled experiments on mosquito larvae before making any extensive purchases.

The Tennessee Valley Authority used in 1943 the following specifications for Paris green:

The Paris green must be of a fineness such that approximately 100% will pass a 200-mesh screen and approximately 85% pass a 300-mesh screen. It must contain 55% arsenous oxide with no more than 2½% being soluble in water. The Paris green must be lethal to anopheline larvae when applied in natural breeding areas and shall weigh not less than 75 pounds per cubic foot. Shipment must be made in light metal drums containing about 100 pounds of Paris green.

E. L. Bishop, M.D., Director of Health of the Tennessee Valley Authority, has written us (November 6, 1943) concerning the characteristics of Paris green as related to toxicity to larvae, and as affecting the method of distribution, as follows:

We apply our Paris green chiefly by airplane although some of it is applied by hand dusters and boat dusters. In writing up specifications for Paris green for use in airplane dusting, we are faced with two conflicting factors. In general, the finer the particle size, the more toxic will be the Paris green to *Anopheles* larvae; however, when applying the material by airplane even slight breezes will cause the dust to drift away from the treatment area if the particles are too fine. A number of years ago when the specifications now in use by the TVA, the Army and Navy, the Public Health Service, etc., were written, most of the Paris green commercially available was of a relatively large particle size, and the specifications were, therefore, intended to insure that the material would be sufficiently fine to be effective against *Anopheles* larvae.

However, in recent years there has been a general tendency to decrease the particle size in manufacturing Paris green for general agricultural use in order to increase its toxicity. As a result, most commercially available Paris greens now appear to be of such a fine particle size that it is difficult to obtain satisfactory distribution by airplane because of the greatly increased drift. During the past year, we have been conducting tests to arrive at a particle size specification which would insure the particles being small enough to be ingested and effectively toxic against the larvae, and yet large enough that they could be distributed by airplane without excessive drift. These studies have involved mainly investigations on the maximum size of particles which can be ingested by the various larval instars and the determination of relative toxicities of dusts of different particle size. From this, we have drawn up specifications for a theoretically ideal larvicide for airplane dusting and have submitted these specifications to various insecticidal companies to see how near they could approach them from a practical standpoint of manufacture. Although, as we expected, it does not appear likely that we may be able to obtain a perfect Paris green for airplane dusting from the standpoint of particle size, it does appear that with slight modifications of the manufacturing process we may be able to obtain a Paris green which is much more suitable than that ordinarily found on the market today. We have tentatively selected the following specification with reference to particle size:

> At least 95% shall pass a 200-mesh screen and at least 85% shall pass a 325-mesh screen; at least 75% shall consist of particles 20 microns or greater in diameter (all percentages are by weight).

It appears that this specification or one very similar to it will not be difficult to meet from the manufacturer's standpoint and will greatly improve the efficiency of our airplane dusting for the control of *Anopheles quadrimaculatus*.

In using Paris green, investigations should be made as to the suitability and cost of materials locally available as diluent dusts. Theoretically the diluent should be very finely ground and reasonably uniform in size; it should be inert and of low specific gravity for hand-casting or power-blowing. For aeroplane application a dust diluent of relatively high specific gravity may be desirable.

The electric charge upon the particles of the diluent also has some bearing on the choice of material. Paris green has a weakly negative charge. Hydrated lime has a positive charge, so that any tendency to separate from Paris green under dispersed conditions in the air will be slight, whereas powdered talc has a negative charge, and therefore the Paris green and the talc will tend to separate in the air. Using aeroplanes, where it is desired that the dust be thrown down rapidly onto the water surface, powdered talc may be preferred in spite of the negative charge because its greater density will carry it and the Paris green down rapidly, before appreciable separation has occurred. Using hand dusters, or mechanical dusters from boats, the positively charged and lighter hydrated lime, which will give a longer "float" or "carry," may be preferred.

A wide variety of materials has been used as diluents for Paris green. Powdered talc or soapstone can be obtained finely ground to a definite maximum size, usually at a comparatively low price. It is inert, and insoluble in water. Hydrated lime is available commercially almost anywhere at a fairly low price, but it tends to pack or arch in blowers, will cake on standing for long periods (especially in moist climates), and may be unpleasant to use because of its effects on the skin and nasal passages. It is slightly soluble in water. Common dust has been used successfully, but it may not always be available in quantity, and must be finely screened to remove all coarse particles. Finely ground charcoal is light and floats well but is usually rather costly as compared with other materials. Tufa properly ground would probably be a satisfactory dust, and in regions where loess deposits are available good fine dust can probably be obtained by loess screening.

In addition to application as a dust, Paris green may be applied in liquid form as a spray. Grant, Newman, and Wood[40] experimented on colloidal Paris green as a larvicide. It was found that Paris green dissolved in concentrated ammonia ($NH_4OH$) and then added to large volumes of water produced a colloidal solution of considerable toxicity to mosquito larvae.

The maximum quantity of Paris green soluble in ammonia will vary with the brand and will probably range in the neighborhood of 50 grams per 100 cubic centimeters. In the experimental work a solution of 20 grams to 100 cubic centimeters of concentrated ammonia was used. Five drops of this solution stirred into a liter of water gave a colloidal solution containing about 0.125 gram Paris green per liter, with a noticeable green color, from which the Paris green settled out slowly, taking more than a week for the greater part to be precipitated. Using *Culex apicalis* larvae in half-gallon glass jars, the material in dilutions of 1 to 5,000,000 killed in from nineteen hours to three days. For practical purposes, the rate of application would probably have to be increased to 1 to 2,000,000 or perhaps 1 to 1,000,000 to get greater rapidity and certainty of kill, and to allow a safety factor to care for irregularities in field application. Studies as to toxicity to fish and water fowl should also be made. For convenience of application and reduction of labor costs, the highest concentration which can be used in the spray and still maintain colloidal dispersion should also be determined. This method appears to have interesting possibilities under some conditions, and to be worth further experimentation.

Barber, Rice, and Mandekos[41] have tried a method of applying Paris green without the use of a dust. Ten grams of Paris green are dispersed in 20 cc. of kerosene, and this mixture is agitated with 250 volumes of water and then sprayed. It can also be applied to pebbles, which are thrown into pools and ponds. The kerosene brings the Paris green to the surface of the water.

Covell[42] has presented an excellent summary of the methods of applying Paris green. His book has a very good bibliography, and is especially valuable to mosquito control workers in tropical regions.

### Dichloro-diphenyl-trichloroethane

A material which appears to be a very powerful culicide is dichloro-diphenyl-trichloroethane, which was first synthesized[43] in 1874. It has the composition

2, 2 - bis (p-chlorophenyl) - 1, 1, 1, trichloroethane.

It was prepared by heating an anhydrous mixture of chloral and chlorobenzene with concentrated sulphuric acid. The product occurs as matted needles which melt at 105° C. Apparently it was originally known as the "Swiss insecticide," and has recently been given the trade name of Gesarol. It is also referred to by the abbreviation "DDT." In 1942 certain insecticidal uses of this material were patented[44] (U.S. patent 2,329,074, and British patent 547,874, both being assigned to R. G. Geigy A. G., Basel, Switzerland), the British patent being for insecticidal compositions of the general formula R R′ CHCXXX, in which R is an organic radical containing three carbon atoms, R′ contains five carbon atoms, and X is either chlorine or bromine.

It is anticipated that this material, or some of its derivatives or modifications, may take the place of pyrethrum for the destruction of both larvae and adult mosquitoes, except possibly in aerosol sprays. It apparently is toxic to mosquitoes in higher dilutions than pyrethrins, is more stable and lasting in its effects, and when made in quantity commercially should be less expensive than pyrethrins. Adequate studies of its toxicity to man, birds, fish, and other forms of animal life have not been published as yet, but it is apparently not toxic to man in the dilutions used. The patents claim that it is non-irritative to man in powdered form when mixed with finely divided diluents.

As a larvicide DDT may be substituted for Paris green in dusts, diluting one part with about four parts of powdered talc, or with equal parts of calcium stearate. Approximately the same quantity is used as with Paris green (one-half pound to two pounds per acre of active ingredient), but its effects apparently are more lasting. It can also be dissolved in acetone, from which solution it can be dispersed in water and sprayed; applied in this manner it appears to be several times more toxic than phenothiazine. Dissolved in kerosene or petroleum distillate (2.5 per cent solution), it is highly effective as a larvicide when applied at the rate of 0.1 pound of Gesarol per acre.[45] It can also be dissolved in various solvents such as alcohols, or in cellosolve (ethylene glycol monophenyl ether), and applied to water. In our laboratory, using a solution in ethyl alcohol of a small quantity of DDT made in the laboratory, the following results were obtained with larvae and pupae of *Culex tarsalis:*

TABLE 8. Effect of DDT on *Culex tarsalis* larvae and pupae

| Dilution (by weight) | Number of larvae | Number of pupae | Effect |
|---|---|---|---|
| 1 to 1,000,000 | 50 | – | All killed in 25 minutes |
| 1 to 6,000,000 | 50 | 10 | All larvae killed in less than 12 hours<br>All pupae killed in less than 36 hours |
| 1 to 100,000,000 | 50 | 10 | All larvae killed in 12 hours<br>All pupae killed in 48 hours |
| 1 to 600,000,000 | 50 | 10 | 5 larvae and 6 pupae still living after 48 hours |

In the only field test which we were able to make (December 7–9, 1943), a corner of a drain breeding *Culex tarsalis* was cut off by a small earth dam. The area was six square feet, and the depth averaged three inches. Something over 300 larvae and 100 pupae were trapped in this corner. The water was slightly muddy and had a high dissolved organic content. DDT was applied to give a dilution of about 1 to 100,000,000. At the end of twenty hours no larvae were found at the water surface; very few of the pupae were killed, though many were apparently in distress. At the end of twenty-six hours one fourth instar larva still survived, and six pupae were still alive. Larvae and pupae (controls) in adjacent parts of the drain were normal.

The residue effect of DDT is evidently appreciable. Small glass jars in which a 1 to 1,000,000 dilution of DDT had been used were emptied, and fresh clean water, plus larvae and pupae, was added. The next morning all larvae and pupae were dead. These jars were again emptied and refilled, with the same result.

### Phenothiazine

Phenothiazine[46]—thiodiphenylamine or $(C_6H_4)_2SNH$—has been used by the United States Public Health Service for the control of mosquito breeding, especially *Aedes aegypti*, in artificial containers. It is a pale yellow-green powder, and is practically insoluble in water. It is relatively stable when kept dry, but oxidizes slowly when exposed to air and moisture. In the quantities used against mosquitoes it is non-toxic to warm-blooded animals and to plants, but will kill fish.

For use as a larvicide, phenothiazine is mixed with a wetting agent such as sodium lauryl sulphate or other dry powdered emulsifier. Approximately 10 per cent by weight of wetting agent and 90 per cent phenothiazine is used. Washing powders such as *Dreft* and *Hi-Lo* have been used as wetting agents.

Very small quantities of the phenothiazine mixture will suffice to keep water free from mosquito larvae for several months. From two to four grams per fifty gallons (one barrel) is about the dosage used. For practical application this represents about one teaspoonful per barrel. For small pans or containers a slight amount may be dusted out of a salt shaker carried by the inspector. Another simple method of application is to mix the phenothiazine and wetting agent with a glue of brown flake gelatin, paint this onto paper, and dry. The paper is then cut into small pieces (about one inch square). One square is sufficient to treat about one quart of water.

There seems to be some difference in the toxicity of phenothiazine under different water conditions, and therefore at the start of operations with this larvicide its effects in different concentrations should be determined by tests.

In regions where there is much mosquito breeding in artificial containers phenothiazine appears to be a useful, effective, and relatively cheap larvicide. Its use for preventing mosquito breeding in flower vases in cemeteries is described at page 331.

### Miscellaneous poisons

Matheson and Hinman[47] have experimented with borax (sodium borate) as a larvicide and report that it is effective in concentrations as low as 1.5 grams per liter of water. They recommend it for rain-water barrels and cisterns, and believe it could be used in small pools of water. We also have found borax to have larvicidal properties, but under most circumstances where borax could be used have found cresylic acid larvicide effective and convenient. If an unchanged appearance of the water is a desideratum and plant and animal life is unimportant, borax may be used as a larvicide.

Nicotine sulphate and nicotine have occasionally been used as mosquito larvicides. We have tried *Black leaf 40* at various times on fresh-water breeding but have not found it to possess sufficient merit, in comparison with either stove oil or cresylic acid larvicide, to justify its use. Richardson and Shepard[48] studied the toxicity of nicotine and found that its toxic properties increased with increasing pH values, and that nicotine had greater toxicity than nicotine sulphate, apparently because of its greater volatility.

A great many chemicals have been tried as mosquito larvicides both in the laboratory and in field experiments, and the search for new materials continues. Among new materials, which have been suggested as larvicides and upon which more or less experimental work has been done, are calcium arsenite dust mixed with chalk; white arsenic and copper sulphate; chloropicrin; calcium cyanamide; and rice bran. These have been briefly reported on by Bishopp and Smith[49] in their summary of mosquito work throughout the world, which appears each year and is one of the most valuable sources of information and ideas available to mosquito abatement officials. In general, the materials mentioned in this chapter are those that are practically applicable and economical. New materials are frequently presented to mosquito abatement officials as excellent larvicides by commercial firms or by mere promoters; all such materials should be thoroughly tested out on a basis of effectiveness and cost as applied in the field before use is made of them. Even when available at no cost, they may not be satisfactory for one or more reasons.

For example, we experimented with the exhausted residue of pyrethrum flowers after the extraction of pyrethrum in the manufacture of insect spray. This material is still highly toxic to mosquito larvae, but though it was available to us without initial cost its final cost as applied had no advantage over oil as we had to accept it during the winter months, haul it, and store it until the next spring or summer. Its storage is very hazardous on account of fire danger.

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## XII

## METHODS OF APPLICATION OF OILS AND LARVICIDES

WHEN OIL or other larvicide is necessary as an auxiliary or emergency control measure, its application to a mosquito breeding place should be considered with regard to the suitability, effectiveness, and relative cost of the available methods and types of equipment. The method of application will depend upon the type of larvicidal material selected for a given job, and upon the type and extent of the particular breeding place. Both of these variables must in turn be related to the costs of application.

In the discussion of these problems, it is assumed that the particular oil or larvicide to be applied has been carefully selected and tested, along the lines drawn in the preceding chapter, for its efficacy in killing mosquito larvae and for its suitability to the given locality and to the type of breeding place to be treated. In this connection and with special regard to the cost of application, attention is again directed to the fact that a low price of larvicidal material does not necessarily reduce the final cost of abatement. Even if, for example, crank case oil can be obtained free, the expense of handling and applying it may make the final cost higher than the applied cost of an efficient purchased material.

In addition to the cost of the oil or larvicide, including the expense of handling, preparation, delivery, and storage, any method of application must take into account the following:

Labor cost
Cost of superintendence and office overhead
Operating cost of equipment
Charge for the transportation of equipment, materials, and workmen
Depreciation on equipment
Interest on equipment investment

The total amount of work to be done will also enter into consideration, for unless a fairly large volume of work is required, it will usually not be profitable to invest in expensive power equipment for the application of oils or larvicides, or even to rent such equipment. On the other hand, under some circumstances such equipment (for example, aeroplanes) offers the only means by which the work can be done at all, in which case there is really no choice of method.

### Hand application

For relatively small areas, or for numerous small and widely separated areas, hand application of oils and larvicides is more convenient and less expensive than the use of power equipment. The cost of short, irregular operation, the cost of transporting the equipment, lost time, and interest and depreciation on power equipment under such circumstances more than offset the savings due to greater unit efficiency of power equipment.

The simplest method of hand application of oil is to pour it on the water surface. This is a slow and ineffective method, and is wasteful of oil. Hand spraying equipment is therefore almost universally used. Such equipment sprays the oil or larvicide in partly atomized form, resulting in a much better spread of the material. It also reduces the amount of walking time of the laborer by giving him a radius of ten to twenty feet over which the spray can be applied.

Four main types of hand sprayers are used. The first is a simple container to which is attached a hand operated plunger working in a metal cylinder, so constructed that the air compressed on each stroke is driven at right angles across the upper end of a small metal tube extending to the bottom of the oil container. This stream of air draws liquid from the container and atomizes it into a fine spray. Such sprayers are of small size, and have a limited usefulness in mosquito control work. They may be used in applying pyrethrum spray to small ornamental garden pools or for killing adult mosquitoes in rooms, cellars, or other enclosed places. Simple sprayers of two quarts' capacity may also be useful in house-to-house inspections as they are easily carried and permit immediate treatment of small breeding areas without returning to the truck for the larger sprayers.

The second type of hand sprayer is a closed metal cylinder of from two and one-half to five gallons capacity, fitted with a brass plunger pump which forces air into the container until a strong pressure is built up. To the outlet pipe, which extends to the bottom of the container, is attached a piece of flexible hose and a spray nozzle. A short piece of metal pipe, usually a quarter inch in diameter and about two feet long, is frequently attached to the flexible hose, and the spray nozzle attached to the far end of this pipe. In operation, the tank is filled about three-quarters full with oil or larvicide, the plunger is operated to produce the required air pressure, and the sprayer is then used until either the liquid or the air pressure is exhausted. Usually several air pumpings will be required before all the liquid in one filling is used. This type of sprayer is handy and portable, and is most applicable to small areas, or where dense brush makes it difficult for workmen to get through with knapsack sprayers on their backs. Many of the cylinder sprayers are cheaply and lightly built, and are damaged easily in mosquito abatement work. We have had the best results with the Myers "Kwik-fil" sprayer, which is sturdily built to withstand hard usage.

The third and fourth types are knapsack sprayers. The liquid is contained in metal cans of about five gallons capacity, carried on the backs of workmen. In one type of knapsack sprayer the liquid is fed by gravity through a flexible hose to a pump mechanism which is held in one hand and operated by the other, being alternately pushed out and in to force the liquid through the spray nozzle. The other type has the pump set in the container, and is operated by a lever extending over one shoulder. A flexible hose extends from the pump to a short piece of quarter-inch pipe connected to a sprayer nozzle. There is still another type of knapsack sprayer which is operated by a diaphragm pump in the bottom of the tank, but which is not satisfactory for oiling operations. The rubber diaphragm will not stand up under the action of oils, and when the tank is only partly full the handle motion is such that the tank will shift and tend to cause sore backs on the laborers.

For general spraying in country clear of heavy brush we find the knapsack sprayer with overhead handle the most satisfactory hand equipment. The principal defects in such sprayers are in the container and in the hose. The container is usually not constructed to prevent spilling of the liquid over the backs of the workmen, and considerable soreness and discomfort often result. We have tried various protective coats for the workmen, but in hot weather these will not be used. The best device for curing the difficulty is that developed by the Dr. Morris district at Bakersfield, California, which consists of a galvanized metal can with a lip about one and one-half inches high extending around and above the top. This lip prevents the spilling of any liquid over the backs of the workmen. The bottom of the can should also be protected by an additional reinforcing iron strip about one inch wide, brazed or welded on.

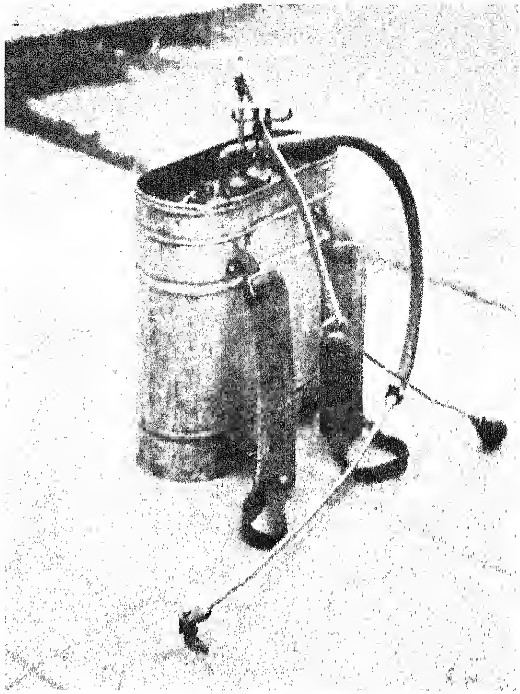
The ordinary hose supplied with these sprayers disintegrates rapidly under the action of oils and oil emulsions, seldom lasting more than a few weeks in service. It requires early replacement. Hose made with *Neoprene* or other oil-resistant synthetic rubber should be specified. Well-made hose of this type will withstand oil action for several years if given good care. We have found that flexible metallic hose is not satisfactory as the soldered joints leak easily and require constant repairs.

Spray nozzles are at present both a problem and a gamble. Our observations indicate that the nozzles available at moderate price have defects in the form of spray, in adjustability, or in other respects resulting in waste of material during spraying, or in ineffective or uneven application. The standard "Bordeaux" nozzle, which is the best available for general low-pressure spraying, causes an appreciable loss of material due to a constant drip off the bottom of the nozzle. There is need for a better type of moderate-priced spray nozzle for this service. Spray guns for high pressure (200 pounds per square inch, or greater) are available, which are quite satisfactory.

On flat areas with short "carry" to reach the work, one man with a knapsack sprayer can spray about five acres per day of eight hours. Long carries and dense vegetation will considerably reduce the amount of ground that can be covered per day. Under especially difficult conditions as little as one-half an acre per day will be sprayed. The amount of area covered will also depend on the amount of actual water surface to be sprayed. An area with scattered isolated pools will require less material and less labor time on spraying but more labor time on carry than an area which is nearly 100 per cent water surface.

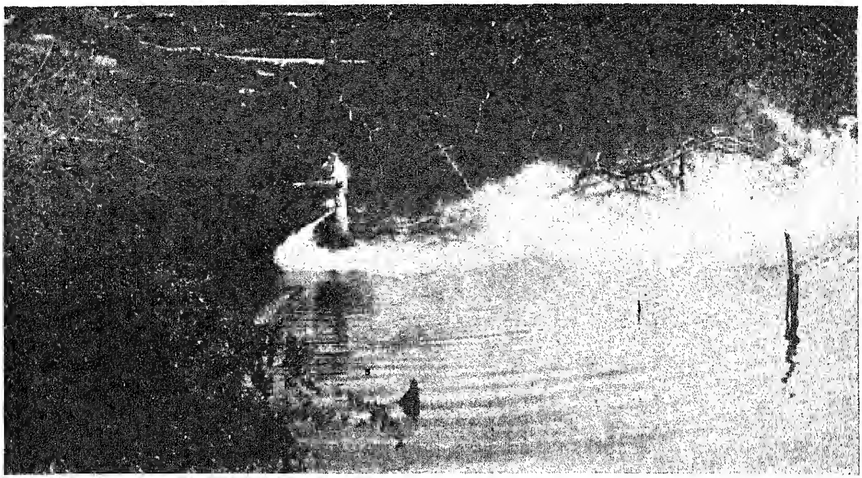
Liquid larvicides may be readily applied by the cylindrical hand sprayers. Usually such larvicides are first diluted with water (about one to ten) in the sprayer. In treating fire barrels and other water vessels of moderate size, undiluted larvicide can be poured into the vessels and thoroughly stirred by a stick, but in general we find that application by a sprayer is most satisfactory, and that supplementary

Figure 58. Knapsack-type oil sprayer with special high-lip top to prevent spillage. Note also straps padded with sponge rubber



*Courtesy The Macmillan Company*

Figure 59. Aeroplane, equipped with four rotary pumps on rear edge of lower wing, applying oil to a mosquito breeding marsh



*Photograph by J. A. LePrince*

Figure 60. Applying Paris green with a hand-operated cotton duster

*Courtesy U. S. Public Health Service*

Figure 61. Applying Paris green by a power blower mounted in a boat

stirring of diluted larvicide is unnecessary, as the material diffuses readily.

Soluble solids such as borax can be applied by measuring out the appropriate quantity and broadcasting it by hand, or simply adding it by hand to water vessels and stirring it until dissolved.

### Hand application of Paris green

Paris green dusts can be applied by hand broadcasting. It is necessary to exercise precautions in either hand-casting or mechanical (blower) application of Paris green, to avoid the danger of poisoning the laborers. The hand-casting or blowing should be done with the breeze, so that the material floats away from the workman; the men should be cautioned to keep their fingers and hands out of their mouths, and after working with the material they should take a complete soap and water shower bath. It is also desirable that the working clothes be washed frequently to prevent any accumulation of Paris green. Chalam, in India, reports that he has done considerable hand-casting of Paris green dust, taking no other precaution than to keep to windward, and has suffered no ill effects. However, with men constantly exposed to the material the precautions set forth should be enforced for safety. Earle[1] reports that in hand-casting Paris green in Porto Rico several cases of arsenic dermatitis have developed.

Soper and Wilson[2] report that in the *Anopheles gambiae* campaign in Brazil in 1940, 1.8 cases of arsenic poisoning resulted per 1000 kilograms of Paris green used. The cases were mostly dermatitis of the hands and forearms, vesicles on the upper lip and nose, scrotal ulcers, and nose bleed. They recommended daily complete bathing, and careful cleaning of the finger nails. Those suffering from persistent or severe cases of arsenic poisoning were transferred to other work, and promptly recovered.

Hackett[3] estimates that one man can prepare and distribute the Paris green over 2000 square meters (21,528 square feet or nearly one-half acre) of water surface per day. He does not state whether this is by hand-casting or by the use of a small bellows blower, but it appears to be by blowers. The stated coverage of slightly less than one-half acre per man per day appears to be very low, and on the face of it would indicate either a low labor efficiency or a relatively very high cost of application of Paris green by hand methods. Under fairly comparable conditions, we would expect one man to apply oil to from three to five acres in an eight hour day, as contrasted with a mere half-acre per day for Paris green.

Soper and Wilson[2] in Brazil applied Paris green by three methods: 1) dry; 2) liquid; and 3) moist. The dry method was used during the dry season when dust or dry fine earth could be obtained locally; the liquid (wet) method was used during the rainy season; the moist method was used in the transitional period between seasons.

For the dry method, one kilogram of dry dust, dry pulverized earth, or even fine dry gravel was mixed thoroughly with ten grams of Paris green, repeating the operation until a bucket was filled to the five kilogram mark. This mixture was then scattered by hand. The duster was provided with a bucket, a small scoop for mixing, a standard measure for ten grams of Paris green, and a supply of Paris green.

For the wet method, a stock mixture was made of Paris green and kerosene or diesel oil at the rate of one gram of Paris green to 2 cc. of oil. This stock mixture is put up in vials holding 25 cc., which are carried in a special type cartridge belt. In the field the contents of one vial is mixed with five liters of water and sprayed from a cylindrical pressure sprayer. Two liters of water, strained through a strainer funnel, are first placed in the sprayer, the Paris green added, and the mixture thoroughly shaken; then the remaining three liters of water are added and well shaken. This mixture is then sprayed, taking care to keep the liquid reasonably agitated.

For the moist method, moist sand, small pebbles, or even coarse dirt is moistened with the Paris green–oil mixture and scattered by hand.

In both the wet and the moist methods the oil helps to bring the Paris green to the water surface.

(Note: for practical purposes liters and quarts are interchangeable—1 liter equals 1.057 U.S. quarts. Also, 30 cc. approximately equals one fluid ounce.)

Various types of hand blowers are available for applying Paris green dusts. In general, the rotary type of blower is better than the bellows type. LePrince and Johnson[4] have developed a simple power blower for dust, which can be operated by one man in a small boat. Using fifteen per cent Paris green in hydrated lime, a path at least

525 feet wide can be dusted with this device in a moderate breeze. If mounted on a truck, it can be used for dusting water near roads.

King and Bradley[5] have experimented with the application of Paris green dust by aeroplane on the swamp lakes in Louisiana. Unfortunately they did not report the costs, in aeroplane time, and incidental labor and expense. Costs at Wilson Dam in Alabama in 1937 are given on page 261.

### Dust application by mortars

Glasgow and Blair[6] have suggested the use of small mortars to explode charges of insecticidal dusts (for instance, Paris green) for mosquito control in mangrove swamps and other areas where access is difficult. Properly placed and fired at the right time and under favorable wind conditions, dust clouds can be driven over considerable areas.

The experimental mortars were made of short nipples of four-inch gas pipe screwed into a standard pipe cap. The firing charge was three ounces of rifle powder for three pounds of dust. They suggest that heavy paper mortars, which are expendable, could be devised.

### Power spraying

Where any considerable area is to be sprayed, the use of power sprayers will be found advantageous, provided the power equipment can be brought within reasonable reaching distance of the area to be sprayed. We have tried out power spraying on the Pacific Coast on several occasions and have found it to be more economical, more effective, and much more rapid than hand spraying. For example, an area near Alvarado in Alameda County, California, was sprayed by knapsack sprayers in September, 1931, and by a power sprayer in September, 1932. The power equipment consisted of a truck-mounted triplex plunger pump driven by a gasoline engine. It delivered oil at 300 pounds per square inch pressure to three-quarter inch hose connections. Two thousand feet of three-quarter inch high-pressure hose were furnished.

Careful records of cost were kept by Clark,[7] and areas sprayed were measured by planimeter from aerial photographic maps. Using knapsack sprayers in 1931, 88.3 acres were oiled at a total cost of

$477, or $5.40 per acre. Using a power sprayer in 1932, 85 acres were sprayed at a total cost of $266, or $3.12 per acre.

The very definite advantages of machine spraying are best shown by the following tables of comparison:

| *Machine Spraying* | | *Hand Spraying* | |
|---|---|---|---|
| Cost per acre | $3.12 | Cost per acre | $5.40 |
| Gals. oil per acre | 22½ | Gals. oil per acre | 32 |
| *Man-Hours per Acre* | | *Man-Hours per Acre* | |
| Labor | .86 | Labor | 5.0 |
| Foreman | .37 | Foreman | .72 |
| Supt. | .37 | Supt. | .37 |

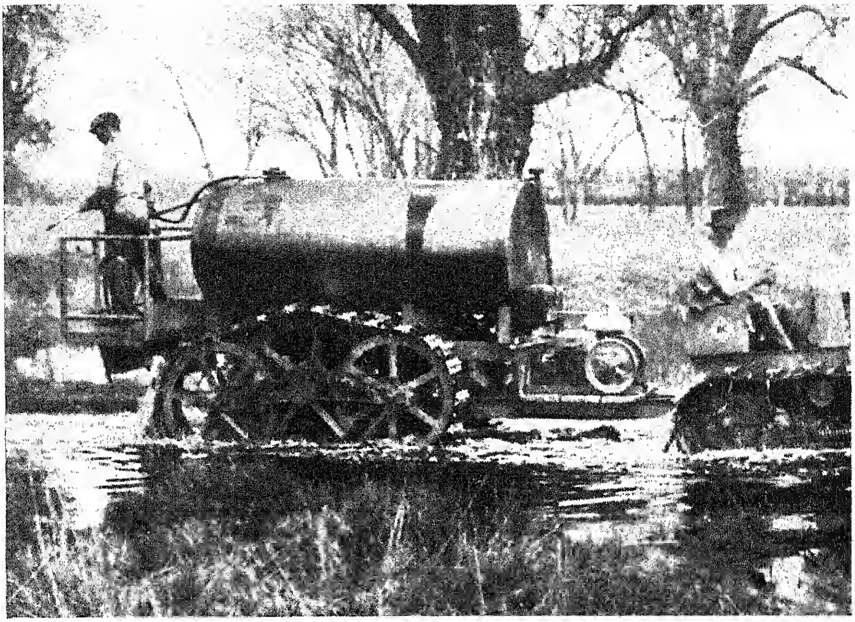
Doane and Steel[8] used the same equipment at Palo Alto, California, in 1932, and found that it cost from 2.7 cents to 3 cents per gallon to apply oil with the power sprayer, as compared with a cost of about 12 cents per gallon using knapsack sprayers. The much greater speed with which the power sprayer covered the area was an important factor.

Clark[7] made an investigation to determine whether it would be more economical to own power spraying equipment or to rent it as required. A power sprayer, with 2000 feet of high-pressure hose and fittings, costing $698 in 1932, was selected for comparison. The fixed annual charges on this equipment were as follows:

| | |
|---|---|
| Interest @ 5% | $ 35.00 |
| Depreciation on hose and fittings—50% on $305.50 (Life of hose considered to be 2 years) | 152.75 |
| Depreciation on machine—20% on $392.00 (Life of machine considered to be 5 years) | 78.40 |
| Repairs for equipment—7½% on $392.00 | 29.40 |
| *Total Fixed Annual Charges* | $295.55 |

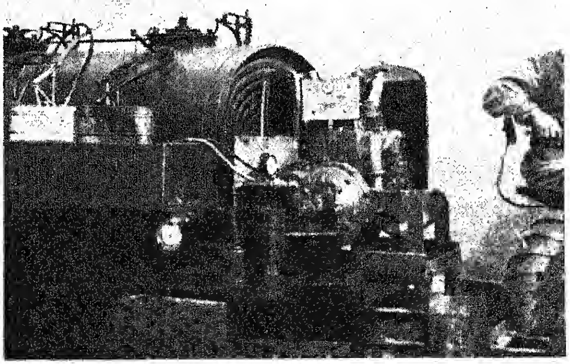
The daily operating costs were estimated to be:

| | |
|---|---|
| Operator | $6.00 |
| 5 gals. gasoline | .90 |
| 2 qts. oil | .52 |
| 20 miles transportation @ 10¢ per mile | 2.00 |
| *Total Daily Cost of Owned Equipment* | $9.42 |



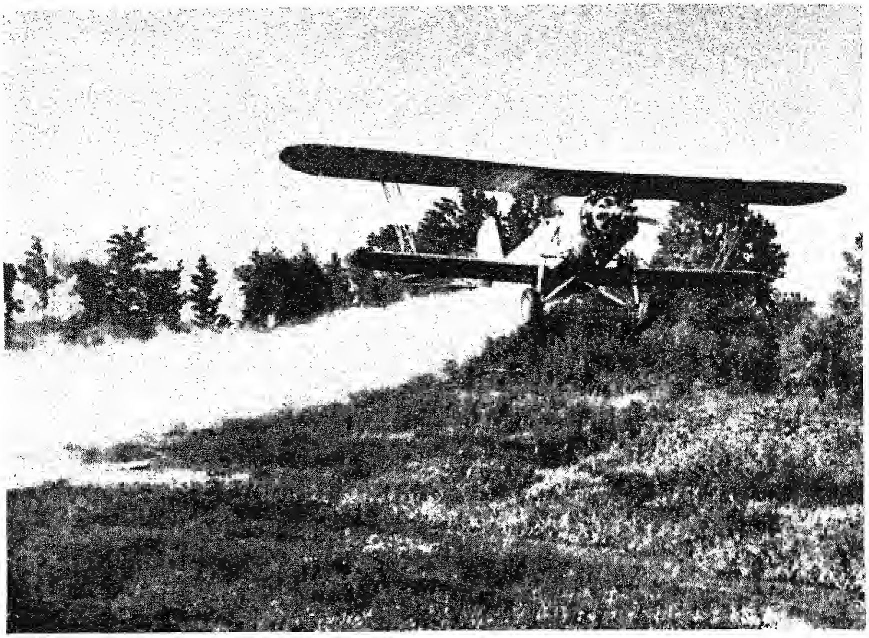
*Photograph by F. L. Hayes*

Figure 62. Tractor-drawn tracklayer-type trailer with oil tank and pump equipment for oiling extensive shallow flood waters



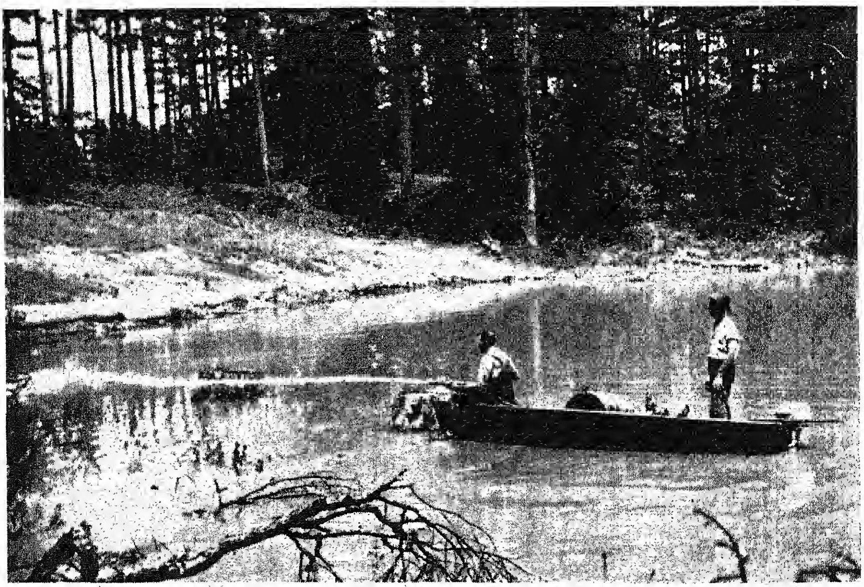
*Photograph by F. L. Hayes*

Figure 63. Rubber-tired trailer oiling equipment used in extensive flood water areas



*Courtesy U. S. Public Health Service*

Figure 64. Aeroplane applying Paris green dust to a marsh



*Courtesy U. S. Public Health Service*

Figure 65. Applying oil by means of a stream of water

The daily rental charge for a similar machine was:

| | |
|---|---|
| Rental @ $1.50 per hour (including operator) | $12.00 |
| Transportation—20 miles per day @ 10¢ per mile | 2.00 |
| *Total Daily Cost of Rented Equipment* | $14.00 |

Clark[7] concluded as follows:

Consequently, there is apparently a saving of $4.58 per day in favor of owning a machine, assuming that the depreciation and repair charges on owned equipment, and the rental charge on rented equipment, remain the same as stated.

However, before any actual saving is effected, the fixed annual charges must be met by the savings of the operation of an owned unit as compared with the rental of equipment. Therefore, the $295.55 fixed annual charges must be divided by the daily saving of $4.58, giving as a result 65 days. Hence it is apparent that if a district has to oil large marsh areas for more than 65 days in a year it would be advisable to buy and operate its own outfit, but if less than 65 days' oiling work per year is to be done, it would be more economical to rent a machine from some commercial orchard sprayer.

On the basis of our experience and investigations of power spraying of marshes for mosquito abatement, we have drawn the following conclusions:

1. Power spraying is much superior to hand oiling for large areas of marsh, particularly if covered with much vegetation.
2. Power spraying is cheaper in materials, labor and total cost than hand spraying, over any considerable area of marsh.
3. If a District has 70 days or more per year of extensive marsh oiling, it will probably prove more economical to purchase and own a power spraying equipment of the type herein described; if not, rental of such equipment will probably be more economical.

The same general method of cost analysis is valid today, substituting, however, present wage and interest rates and prices.

Since 1941 we have used effectively and economically a Bean Orchard Sprayer, with a fifty-gallon tank and a Van Pelt hose reel, mounted on a trailer made from a Model A Ford frame and running gear. Complete with 900 feet of high-pressure hose, the equipment cost $696.

One type of pump equipment which appears to have possibilities, but which we have not seen tried, is the small gear-tooth rotary high-pressure pump. This pump can be attached by a gear train and clutch to any truck engine which has a power take-off. Such pumps will deliver two or three gallons per minute at about 250 to 300 pounds per square inch pressure. The pump with gears, clutch, and housing can be installed under the hood for about $75. Hose, nozzles and fittings would be additional. The power efficiency using the truck engine to drive such a small pump would be very low, however.

Some of the county mosquito extermination commissions in New Jersey use tank trucks, some with considerable liquid capacity, the trucks being equipped with special pumps for spraying.

The New York City health department has also developed and uses successfully tank trucks combined with power spraying units. Obviously, large heavy tank trucks can operate successfully only where hard surfaced roads or very firm, fairly level ground permits them to get within reasonable hose lengths of the breeding area.

Extensive areas of shallow water a few inches to two or three feet deep, standing upon soft ground or marsh, may present a very difficult problem. Permanent shallow flooding should be handled by drainage, but in certain types of terrain the backwater from floods cannot be so controlled, and mosquito abatement may then be a serious and expensive problem with ordinary equipment. Much of this type of flooding is too deep to wade in and too shallow to row a boat on. Several types of equipment have been devised for the purpose of penetration through or travel across such areas. Contractors and engineers working in extensive swamps have developed an amphibian rig, with a boat body and very large pneumatic tires, which can progress on both land and water. By installing oil tanks and a high-pressure pump and sprayers, this type of equipment can cover almost any type of flooded area, oiling as it goes, and is not stopped or stuck by sloughs or potholes. It is also able to penetrate ordinary jungles of brush or other vegetation. The military amphibious landing barge would make an excellent vehicle for this type of work, if available after the present war.

J. L. Clarke[9] has developed several types of mechanized equipment for the rapid and economical application of sprays under difficult ground conditions. Large-tired (13½ x 24) four-wheel-drive trucks with power spraying equipment are variously designated as "marsh buggies," "skeeter-eaters," "swamp angels," "puddle-jumpers," and "dinosaurs." The "skeeter-eater" cost $4200. Clarke also uses a power barge for spraying. He is enthusiastic concerning the performance and economy of this mechanized equipment in the Des Plaines District in Illinois.

F. L. Hayes of Bakersfield, California, has developed tractor-type equipment with trailers for shallow floodway oiling. His first machine was mounted on very large pneumatic tires, with the trailer carrying a 500 gallon oil tank and the pump. His second machine is powered by a Caterpillar 35 tractor with twenty inch treads, the trailer also being mounted on twenty inch tracklayer treads. The trailer mounts an 800 gallon oil tank, pump, and spraying equipment, and is provided with a stout railing to keep the workmen from being tossed off the trailer when progressing over rough ground. An extra 150 feet of hose is carried on a reel, with which to reach places difficult of access.

These rigs operate successfully in a two foot depth of water and with reasonable precaution seldom require help to get through. They are used for oiling the floodway of the Kern River after the floods, a large area which produces immense crops of *Aedes vexans* and *Culex tarsalis.* The rigs cover this area effectively within the time limit necessary to prevent flights of *Aedes vexans*, which in years of heavy floods could not be successfully done by hand spraying methods. If a Peerless-Bean orchard-spray gun with 185 pounds pressure is used, one nozzle can oil a windrow about 120 feet wide at two and one-half miles per hour on reasonably open ground. As two men are usually worked, one on each side of the trailer, a strip over 200 feet wide can be covered, which would be at a rate of about fifty-six acres per hour, or 448 acres per day. Time lost in travel to replenish the oil, difficult ground, and other delays probably reduce the total area per day somewhat below this figure.

The relative cost advantages of power spraying with mechanized equipment will vary. Obviously, a comparatively large volume of spraying work is necessary to justify the investment cost of such equipment, if cost alone is a controlling factor. Where large volumes of spraying of extensive areas are required, the question always occurs, "Would not the cost of drainage, fill, or reclamation be less than the capitalized cost of such spraying?" or "Could not naturalistic control measures be profitably substituted for spraying?" Of course, where wage rates are high a greater mechanization will be justified than where wage rates are low, and where labor is very scarce, complete mechanization may be necessary. Complete mechanization may also be necessary where the nature of the ground is such that men on foot cannot cover the area, and it may also be essential where there are restricted time limits in which to destroy a mosquito hatch.

### Application of oil by a water stream

One of the best methods of applying oil on a reservoir or other relatively large body of water is to use a strong stream of water as the propelling medium.

A small (one and one-half inch) gasoline-motor-driven centrifugal pump may be mounted in a launch, taking its suction from the reservoir water and discharging through a length of hose fitted with a fire-type nozzle. Oil is introduced by a small (one-half inch) pipe from an oil barrel, connected to the pump suction pipe, the rate of oil feed being controlled by a valve in the oil feed pipe. Such a pump can throw the oil-water mixture 100 feet or more, well beyond the range of hand or pneumatic sprayers, especially against a wind. The strong water stream will also break up floatage masses and carry the oil through vegetation into protected breeding places. With the equipment described, the boat can be kept off shore in deep water, thus reducing the possibility of propeller damage or of lost time from grounding. While the water pump can be connected to the engine of a power boat, it is recommended that for flexibility in operation the pump have a separate engine. For the same reason, power blowers for Paris green, when mounted in boats, should have a separate engine directly connected to the rotary blower.

### Comparative costs of applying larvicidal materials

It is unfortunate that adequate data on the comparative cost of applying oils, Paris green, and other larvicidal materials are not available. Apparently few mosquito abatement agencies attempt to analyze the cost of such operations, and to break them down into component parts on a logical basis of unit quantities of work performed, so that valid comparisons of costs can be made.

Units of work performed would have to be generally accepted as a basis of unit costs. For swamps and marshes, the area in acres is probably an acceptable base for measurement of work performed, but it is difficult to define "area." Shall "area" be limited strictly to water surface only, or shall the entire marsh area be included? If the former, how much effort is justified in measuring the actual water surface treated? Can an estimate of the percentage of marsh surface covered by water be sufficiently close for reasonable unit cost estimates?

The measurement of some types of larvicidal work is not readily expressed on an area basis. The unit base for relatively narrow ditches or small stream beds is more easily and perhaps more logically expressed as a length, though measurement of work on wide ditches and stream beds can be expressed as an area. A good deal of larvicidal work is on a "spot" basis, for which neither area nor length is adaptable as a measure.

After acceptable units of measurement of work are agreed upon, there is still the problem of what items enter into costs, and in what terms they should be expressed. Labor should be expressed in man-hours, and power equipment in machine-hours, as well as in terms of money. There can be much variation in the establishment of price rates for machine time, and wages vary in different regions. Materials should be recorded quantitatively in gallons, pounds, or cubic feet, as well as in money cost, in order to evaluate price variations. Accessory costs, such as transportation and supervision, should also be recorded and included, but these will vary widely unless a standard accounting method is used.

Until some comparable system of unit costs is adopted, it will not be possible to evaluate claims, for example, that pyrethrum larvicide is cheaper than oil, or that Paris green is cheaper than either. It is hoped that some organization conducting mosquito control operations over a considerable and varied area, and using different types of larvicidal materials, will undertake a well-planned study of methods of collecting, recording, and analyzing these costs, and of actual costs as they work out under a valid cost system. Too many snap judgments and possibly unwarranted claims have been and are being made in this sector of mosquito control practice.

### Application by aeroplane

Application of oils or dusts by aeroplane is practicable under certain definite conditions: 1) when the ground is so soft that access on foot or by trucks is impossible or exceptionally difficult; 2) when the areas to be treated are extensive and continuous or practically continuous; and 3) when it is important to obtain sufficient speed of application to prevent the emergence and flight of mosquitoes from extensive breeding areas. The last condition might obtain, for example, where a flood was followed by warm weather, resulting in an unusual abundance of larvae in the flooded area. Ground transportation under such circumstances would be slow, difficult, and uncertain.

The mechanism for applying oils from aeroplanes is varied. In New Jersey a simple pipe system attached to the tail of the plane has been used, the oil flowing by gravity from the main tank to lateral pipes at the tail of the plane. Dependence for breaking up the oil and distributing it was put on air turbulence in the rear of the plane.

Another type of mechanism for applying liquids consists of two or more rotating pumps set at the rear edges of the lower wings of the plane, connected by shafts running forward to the front edges of the wing to small wind-actuated propellers. The forward motion of the plane causes the propellers to turn, rotating the pumps which throw the liquid outward in all directions into the slip stream. The fineness of spray can be regulated by the speed of rotation of the pumps and by the size of openings in the pump. In order to get ten to fifteen gallons of oil per acre (about the minimum amount practical) relatively large pump passages are necessary. The size of the feed pipe from the supply tank to the pumps should be reasonably large, one and one-half inch or even larger.

We obtained a very satisfactory distribution of diesel oil on salt marshes with an aeroplane so equipped. The price of application was twenty-five cents per gallon and the price of the oil four and one-half cents per gallon. The cost on an area basis was roughly $4.30 per acre, using the oil at a rate of about fifteen gallons per acre on an area of about one hundred acres. Practically 100 per cent kill was obtained in twenty-four hours.

The usual apparatus for applying dusts by aeroplane is a Venturi tube. This is simply a rectangular sheet metal tube, constricted at the center and flared at each end, and placed below the fuselage of the plane longitudinally to the direction of flight. The forward motion of the aeroplane in flight causes a high velocity at the constricted throat, at which point the dust is introduced into the air stream. The great air turbulence in the rear expanding section plus the turbulence of the slip stream of the plane causes the dust to be well disseminated. The Venturi tube may also be used for the application of liquids. The dust or liquid is carried in a hopper mounted near the center of balance of the aeroplane, and the rate of discharge is controlled by a slide valve or similar mechanism. A rotating helix, paddle, or other device in the hopper may be needed to prevent dusts from packing or arching in the throat of the hopper.

The cost of aeroplane application of liquids and dusts is influenced by the following factors:

1. The length of "run"—long lanes of flight in applying the material are less expensive than short lanes, because less time is lost in turning to start back on the adjacent lane
2. Distance from the loading base to the place of application
3. Load capacity of the plane—the larger the load the less time is lost
4. Special hazards

Aeroplane application is usually contracted for on the basis of a price per gallon of liquid or per ton of dust. A basic price for a so-called standard run and distance can usually be obtained, subject to modification according to local conditions. For areas at a considerable distance from the home airport of the flying company, an extra charge for travel to the location of operations is usually made. Unless the area to be treated is rather extensive (say 5000 acres or more) this item is apt to be a significant part of the cost of aeroplane application.

Aeroplanes may also be contracted for on the basis of an hourly charge for actual application time, another hourly rate for idle (nonflying, including loading) time, and a mileage charge for ferrying or transporting runs between the operations base and the area of application.

Kiker, Fairer, and Flanary[10] at Wilson Dam in Alabama, in 1937, found the following quantities and costs on large-scale contract aeroplane dusting for the Tennessee Valley Authority:

| | |
|---|---|
| Total dusting days | 72 |
| Time aeroplane was flown | 195 hours |
| Average flying time per dusting day | 2¼ hours |
| Cumulative total extent of dusting | 73,000 acres |
| Total flying cost | $8,350 |

| | |
|---|---|
| Flying cost per hour | $43 |
| Amount of dust distributed per hour | 1,300 pounds |
| Area dusted per hour | 373 acres |
| Amount of dust per acre per application | 3½ pounds |
| Flying cost per acre per application | 11 cents |
| Dust cost per acre per application | 26 cents |
| Total cost per acre per application | 37 cents |

In this work the Paris green was reported to have been applied at the rate of about one pound per acre per application, after preliminary trials and checks had indicated that a rate of one-half pound per acre per application gave a non-uniform and inadequate control of the breeding of *Anopheles quadrimaculatus.*

These costs are reported to compare favorably with an estimated cost of ninety cents per acre per application using boats and hand dusting. However, both costs appear to be understated. For example, the aeroplane costs apparently do not include a pro-rating of the cost of three landing fields, or of the dust handling, mixing, and transporting equipment, or depreciation, or the cost of technical supervision, superintendence, and overhead. If all costs properly chargeable to the operations were included, the true total cost per acre per application apparently would be considerably higher.

Where large-scale aeroplane dusting operations are to be undertaken, the following points should be given due consideration to insure effectiveness and economy:

1. The methods of purchasing, handling, mixing, and transporting the dust ingredients and mixed dust must be carefully studied in advance. Probably a central mixing depot, with warehouse, an airveyor unloader, receiving bins, a motor-powered mixer, and a bagging machine, located on a railroad siding for carload lot shipments, will be best.
2. Paris green and the diluent should be purchased on competitive bids under definite and rigid specifications. Each lot of Paris green and of diluent should be analyzed and tested for conformity to the specifications. Variations in weight of the diluent should be taken into account in preparing the mixed dust, so as to obtain uniform results upon application.
3. The mixed material should be bagged in fifty pound five-ply moisture-proof paper bags, and transported to the landing fields in trucks or barges.
4. Both non-dusting flying time and non-flying time should be reduced to the minimum possible. This may require the construction of a

number of landing strips, with runways about 2000 feet long and 300 feet wide, strategically located so that the distance from loading field to the furthest point of application does not exceed five miles; a loading crew of about three men, with an easily moved loading ladder-platform; and a dust warehouse.

5. Flying obstructions or hazards, such as isolated trees or small groups of trees along the dusting area or near the landing fields, should be removed if possible. Non-removable flying hazards should be shown on the pilot's maps.
6. Flying must usually be done early in the morning as soon as sufficient light is available for visibility, to avoid excessive wind drift. In some cases late afternoon calms may permit dusting.
7. The aeroplane should be specifically designed for this type of service (for example, crop-dusting aeroplanes) with relatively thick, high-lift aerfoil profiles, good load capacity, and great maneuverability. The dusting speed should be relatively low.
8. The aeroplane should be provided with a Venturi type throat with a slotted feed of adjustable length, calibrated as to rate of discharge at various lengths of slot, and operated from the pilot's seat. The Venturi throat preferably should be adjustable in depth of throat.
9. The dust load should be carried in a hopper of adequate capacity, probably 600 pounds or more, located as near as possible to the center of gravity of the aeroplane. Within the limits of aeroplane capacity and maneuverability, the greater the "pay-load" the less the lost time in non-dusting flight and in reloading. The hopper should be made absolutely dust-tight. To insure uniform delivery of dust to the Venturi throat, the hopper should have two agitators, one close to the throat, which may be driven by an impeller located on the front edge of either wing. The interior of the hopper should have absolutely smooth sides, with no sudden changes in direction. The hopper should have a dust-tight charging opening at the top.
10. The fuselage should be dust-tight, especially the tail, to prevent dust from coming into the rear portion and working forward. Pilots have experienced unpleasant after-effects from inhaling Paris green dust.[11]
11. The width of strip or swath flown will depend upon conditions, but 200 feet at a flying height of twenty-five to thirty feet appears to be usual for average conditions. Strips should be lapped slightly to insure thorough coverage. With dense low vegetation the aeroplane may be flown closer to gain the propeller turbulence effect in kicking the dust through the vegetation to the water surface.
12. The effectiveness of dusting should be continually checked by exposure in the path of the aeroplane of dust particle slides (glass slides coated very lightly with petrolatum or similar material), by

dipping before and after treatment to determine the relative numbers of larvae, and by hand or trap catches of adult mosquitoes.

13. It will be wise to arrange flying time and aeroplane and ground equipment so that regular scheduled dusting can be completed in the first three days of each week. This leaves the last three days of each week as a safety margin for adverse weather conditions, emergencies, or for re-flying where the tests show an unsatisfactory kill.
14. Landing fields, warehouses, depots, equipment (for mixing, transporting, and loading dust), loading labor, inspection services, and planning and supervisory personnel should be provided by the mosquito abatement agency. Aeroplane equipment and pilots may be furnished by large mosquito abatement agencies, but under most conditions it will be cheaper and better to contract for flying services with an established crop-dusting concern, upon competitive bids. The advice of such concerns on many of the details of aeroplane application of dusts will be found to be very valuable.

W. C. Murray and H. Knutsen of the United States Public Health Service (unpublished data made available to us), in treating during 1943 water-chestnut or water-caltrop (*Trapa natans*) covered areas in the Potomac River below Washington, D. C., and a few adjacent marshes, applied by aeroplane 40,277 pounds of Paris green mixed with 134,955 pounds of powdered soapstone. The total area dusted accumulated to 32,536 acres, during an aeroplane dusting time of 243¾ hours.

This represents an average dosage of 1.24 pounds of Paris green per acre; the maximum rate of application was 1.52 pounds per acre. The ratio of Paris green to diluent was roughly one to three (40,277 ÷ 175,272 = 23%). On a dusting-time basis, the rate of application was about 720 pounds of mixed dust per hour. The overall average plane flying time was about forty-five minutes to 100 acres, which included some long runs to relatively distant marshes.

The total cost of the work, not including the commissioned personnel directing the work, was $36,278.80, divided as follows:

| | |
|---|---|
| Aeroplane costs | $23,256.84 |
| Materials | |
| Paris green at $21.80 per 100 lbs. | 8,780.39 |
| Soapstone at $9 per ton | 607.50 |
| Labor | 3,354.07 |
| Incidentals | 280.00 |
| Total | $36,278.80 |

The unit cost was $1.12 per acre per application.

The type of aeroplane used was a two-place Stearman biplane with a hopper capacity of 600 pounds. Aeroplane time was paid for at the rates of $70 to $80 per hour of dusting time, and $8 per hour for stand-by time; ferrying mileage to points of application was charged at the rate of 75 cents per mile.

During the dusting, they experimented with a "sea-sled" type of boat, with an air propeller as the motive power, as a means of getting about on water covered with dense aquatic vegetation.

### Oiled sawdust

Under some conditions, sawdust impregnated with oil can be used successfully where sprayed oil does not seem to be effective. The sawdust should be soaked in a petroleum derivative oil, drained free from excess oil, and preferably held for several days before application. This can be hand cast. It seems to be most useful in cracks or crevices not easily reached otherwise and also where a more continuous film of oil is necessary on account of difficulty in getting to the breeding places, or where vegetation impedes the spread of oil. It is also useful in the control of mosquito breeding in rice fields, and in combating the mountain *Aedes* species, the larvae of which appear as the snow melts. Oiled sawdust applied just before the melting of the snow, at points of known or probable breeding, retains its oil until the melt and then distributes an effective oil film on any water in which these "snow" mosquitoes would breed.

For continuous oiling, oil-soaked sawdust can be placed in a sack, weighted down with a few rocks, and deposited in a pool or stream. The oil will be gradually displaced by water and fed constantly to the surface until exhausted.

### Drip cans

On sluggish streams or canals where mosquito breeding may occur along the edges, it is sometimes advantageous to maintain a continuous application of oil in small quantity. This can be done by means of a drip can, which is simply a container to hold one or more day's supply of oil, and a feeding device which will drop a regular small quantity of oil onto the water. Drip cans may be posted at the upper end of sluggish streams or canals, and with the drip adjusted to the proper rate by experiment will keep a sufficiently continuous film of oil on the water to stop breeding.

The simplest type is a five gallon kerosene can with a small nail driven through the bottom. A little packing of waste is wrapped tightly around and under the head of the nail to retard the flow of oil. Our experience with this simple device is that it cannot be regulated with any degree of satisfaction, and gets out of order easily. Where drip cans are required, we consider it worth while to purchase heavy galvanized five or ten gallon cans, and solder or braze a quarter inch brass petcock into the side of the can near the bottom. The petcock can be opened slightly to produce the drip required. If the drip can has to be placed in a position where it can be easily tampered with by the curious or malicious, the entire apparatus can be enclosed in a protecting wooden box with a hinged and padlocked side opening and a partially open bottom.

For convenience in filling and inspection, drip cans should be placed near roads and may be set on bridges or other structures upon waterways. If such structures are not available, a support for the drip cans can be built with two-by-four inch lumber. The cans should be several feet above the water surface, so that the splash from the drops striking the water surface will give a better spread.

The lighter oils such as the distillates and diesel oils will work better in drip cans than heavy or viscous oils. If there is any appreciable vegetation, an oil with high toxicity and high spreading coefficient should be used.

Russell[12] devised a mechanism consisting of a metal bin and an inclined and baffled dash-plate for automatic application of Paris green and sand mixtures to streams in the Philippines. By its use a considerable reduction in the stream-breeding *Anopheles minimus flavirostris* was obtained. Recently Knipe and Russell[13] have devised improved automatic equipment for applying Paris green dusts to streams. If such devices are properly located and continuously operated, they should be useful in the control of stream-breeding *Anopheles*.

### Precautions in applying oils and larvicides

Reference has been made in the preceding chapter to special precautions which must be taken in applying oils or larvicides to prevent damage to growing crops, livestock, or gardens, or to eliminate special hazards.

Frequently we find in irrigated districts that residual water will collect in low areas of irrigated fields and remain for a sufficiently long time to produce and mature a crop of mosquitoes. If, as is frequently the case, this water stands among the growing crops, there would be material damage if it were oiled. Every effort should be made to conduct such excess water away from growing crops by means of drain ditches, or at least reduce it to a level which can be oiled without danger of damaging any growing crops.

We have found that some types of oils, especially the stove distillates, when applied to water standing on grasses which are used for cattle feed, seem to have a deleterious effect upon grazing animals, causing digestive disturbances and loss of weight. Under identical conditions, where an unrefined distillate has caused damage to cattle, we have been able to use water-white kerosene without the slightest bad effect on cattle. We have frequently seen cattle, grazing where the kerosene was being applied, drink the water with kerosene on it, without objection and with no known bad effects.

On marshes frequented by wild fowl, it is important to avoid the use of heavy oils such as crank case or crudes, as these frequently do damage to the birds, apparently by gumming their wing feathers so as to make their flight impossible. As a result, many such water birds are killed. One of the first objections from duck clubs when oiling is proposed arises from the fear that such heavy oils may be used to the damage and destruction of marsh bird life.

It is undesirable to use inflammable oils of any type on wet areas under wooden buildings, as they may cause a fire hazard. Also, light oils with any considerable volatile content should not be used in enclosed spaces where an explosion hazard may result, without taking special precautions so that open flames will not be used as long as the explosive mixture of air and oil persists. In oiling underground street vaults of gas, water, and telephone utilities, this condition may easily occur. The Pacific Gas and Electric Company has tested street vaults after oiling with distillates and kerosenes, and has found that dangerous mixtures do occur.

In the immediate vicinity of food handling establishments, larvicides with noticeable odors, such as cresylic acid larvicide, may not be used because the odor may be absorbed by some types of food. We remember one case of intense breeding under a bakery, caused by a broken sewer drain, where we could not use larvicide on account of the smell, and were afraid to use oil on account of the fire hazard. We had to let the neighborhood complain for a week or more until the drain was repaired and the water dried up.

Oils should also be used with caution about gardens and garden pools. This is discussed in CHAPTER XVI.

USE OF ALGICIDES

Under some types of shallow water conditions the growth of various types of algae (green slimes or moss) becomes so dense that not only are the activities of fish impaired but applications of oil become ineffective or only partly effective. When this is found to be the case, it is advisable to apply an algicide such as copper sulphate to kill off the organic growths. The dosage required to kill the types of organisms which give the mosquito man trouble is about two pounds per million gallons of water. Dosages larger than three pounds per million gallons should be avoided in ponds containing fish, as they will kill trout and less resistant species of fish.

However, consideration may be given to the use of much larger dosages of copper sulphate, either to kill all vegetation, aquatic or emergent, in mosquito breeding water, or to kill off for a considerable period of time the organic food supply of mosquito larvae. If the latter result is obtained, mosquito breeding, especially *Anopheles* breeding, may be stopped or greatly diminished for varying periods.

In moderate sized pools the copper sulphate crystals may be hand cast. In larger bodies of water the copper sulphate is best applied by placing it in sacks and dragging it, especially along the shallow areas, until dissolved. Usually several applications during a season will be required.

For very large bodies of water several devices have been developed in water works practice for the rapid and economical application of copper sulphate. In the Los Angeles Water Department, R. F. Goudey uses a power device for broadcasting granular copper sulphate; G. E. Arnold in the San Francisco Water Department uses a spray of solution.

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# XIII

## MOSQUITO CONTROL BY USE OF FISH

CERTAIN SPECIES of fish are effective natural enemies of mosquito larvae and pupae under appropriate conditions. These are the surface feeders, the active and aggressive types preying on small aquatic animal life. Subject to certain limitations, fish can frequently be used with considerable success as supplements to basic mosquito control measures.

On salt and brackish marshes, the killifishes (*Fundulus*) on the east coast of the United States, and the sticklebacks (*Gasteroperus*) on the west coast, are natural enemies of mosquito larvae and pupae, and few will be found in areas into which these fish can freely penetrate. There are probably other salt and brackish water species in other parts of the world which are effective larva destroyers, provided conditions on marshes are adjusted to their requirements. The most important factor is usually that of access by the fish to all mosquito breeding areas on the marsh, but with some species an interchange or flow of water through tidal action may be necessary. The former can be obtained by properly located ditches; the latter can be accomplished by means of tide gates and weirs.

A number of species of fish have been found useful as predators on mosquito larvae in various parts of the world, and this problem has as yet been investigated only superficially. Adequate study of and experiment with native fishes wherever mosquitoes are a problem should produce results of definite value in controlling mosquito breeding.

Connor,[1] after experimenting with different fish in Ecuador, selected the "chalaco" (*Dormitator latifrons*) as the most satisfactory native fish for use in water containers. These fish have been widely transplanted with good results.

John[2] concludes that in India *Aplocheilus lineatus* is a surface-feeding fish preying on mosquito larvae and pupae by preference. It is capable of adapting itself to varied conditions, and will thrive in deep wells, stagnant ponds, muddy pools, and even in small artificial containers of water.

Job[3] found that in Bengal *Aplocheilus panchax* destroys all aquatic stages of anopheline as well as culicine mosquitoes in clean-weeded railway borrow pits, and that fish control in these borrow pits, including replenishment when needed, costs about one-tenth of the cost of control by the use of Paris green.

*Aphanius* (*Lebias*) *dispar* has been reported to be useful in destroying larvae in Abyssinia and Arabia (Bahrein Island).

Probably the most widely used and best known larvicidal fish are the top minnows of the *Gambusia* genus. The two species most used are *Gambusia affinis* and *Gambusia holbrooki*. *Gambusia affinis* in particular can be adapted to a wide range of climatic, geographic, and water conditions, including brackish and salt water, and even sewage. It apparently can be transplanted successfully into any region where severe winter freezing does not occur, and even under such conditions can survive in selected locations. It has been introduced into various parts of the world, even over great distances, for example, from Texas to the Hawaiian Islands and thence to the Philippines.[4]

### Gambusia affinis

*Gambusia affinis* is viviparous (giving birth to living young), and does not require a special environment. It will thrive in fairly warm water, but dies rapidly under freezing conditions. Because the adults are carnivorous and cannibalistic, it automatically regulates its numbers according to the available food supply. If natural food runs short, the young are eaten until the number of fish is reduced to that which can be maintained under the particular environment.

The female *Gambusia affinis* is larger than the male. Fully grown under normal conditions it is about one and one-half to one and three-quarters inches in length. The male averages about one inch in length when full grown. Occasional specimens are found exceeding these lengths, and under some special conditions numerous specimens exceeding two inches in length (female) may be taken. The young at birth are about one-quarter inch in length.

In color the fish are olive green above and silvery on the sides and abdomen. Seen from above in natural ponds they appear blackish; in a museum jar with side lighting their real color is more easily seen. The anal fin of the male gradually changes into an elongate organ of copulation, characteristic of many species of viviparous fish.

Gravid females can be identified by a black spot on each side of the abdomen in front of the vent. As parturition nears, these spots increase in size and ultimately join on the ventral surface at about the time of giving birth.

A female may have several broods a year, depending apparently on climatic conditions and available food supply. Under especially favorable circumstances, the increase of *Gambusia* is astonishing. Usually the young are extruded singly, and the birth of a brood may take from an hour to perhaps a day. A brood may contain from as few as four or five to as many as fifty or perhaps sixty. The females considerably outnumber the males. The young *Gambusia* grow rapidly, under favorable conditions reaching full size in three or four months.

An idea of the appetite of *Gambusia affinis* for mosquito larvae can be readily obtained by keeping one full-grown female in a museum jar of tap water for two days without food, and then introducing approximately half grown mosquito larvae in batches of ten at half-hourly intervals. Usually the fish will consume well over 100 larvae in eight hours. They are so voracious that small fish have been observed to choke themselves to death trying to engorge larvae as large as themselves.

When *Gambusia* are introduced into a vessel containing larvae of various sizes and pupae, they attack the larvae first, and do not attack the pupae until all the larvae are consumed. Whether this is because the larvae are more easily swallowed or because the pupae tend to rest quietly at the surface and so escape observation is not certain. Undoubtedly the value of *Gambusia affinis* in mosquito abatement work lies principally in their habit of feeding mainly at the surface. Hildebrand[5] has observed that *Anopheles* larvae, as long as they remained absolutely motionless at the surface, were not eaten. Some fish even "nosed" motionless larvae, apparently not detecting that they were alive and edible. The slightest movement by a larva is usually sufficient to cause it to be snapped up. The larvae of *Anopheles quadrimaculatus* are usually motionless and do not attract the attention of top minnows as do the more active larvae of *A. maculipennis*, which may be one of the reasons why the use of this fish in the control of the former species is not so effective.

The public is apt to get some peculiar ideas as to the function of these fish. They are commonly called "mosquito fish" and some ludicrous ideas about their characteristics have had to be patiently explained away. On numerous occasions we have had to insist that the *Gambusia* does not have wings. Some people have naively asked that a water bucket with a few fish in it be placed in their back yard, as they have heard that the fish would catch mosquitoes, which to them meant only the winged adults.

### Breeding gambusia

As the *Gambusia* thrive best in moderately warm water, comparatively shallow breeding ponds are desirable. About two feet of depth in a sunny location in temperate climates (partly shaded in hot climates) is very satisfactory. Ponds that are shallower than this put the young fish (which tend to keep near the bottom in the early weeks of their existence) at a disadvantage in escaping the cannibalistic attention of their parents; much deeper water remains too cold for most rapid development.

Breeding ponds should have considerable vegetation, both as a source of food supply and as shelter for the younger fish. If there is no natural vegetation, water plants should be obtained and planted in the breeding pond. It is also desirable to plant some green algae in the pond. If the growth becomes excessive the algae will have to be raked out several times a year. The breeding pond water does not have to be changed unless badly fouled. Water should be added to artificial ponds as required to make up for evaporation and leakage. Natural ponds are the best and most economical for breeding *Gambusia,* provided they are accessible. It should be possible to get within a short distance of the breeding pond with a truck, and to get to the water's edge easily and safely on foot.

Artificial ponds may be improvised from abandoned reservoirs, but if nothing of that kind is available, they can be cheaply constructed by excavating with a horse-drawn Fresno scraper. A pond 100 feet long by 50 feet wide, divided into two parts by a partition, should be ample for breeding purposes for all but the largest districts. If the earth is a heavy clay and the water supply is ample and cheap, the pond need not be lined. If the soil is porous or water scarce or expensive, either the bottom and sides should be treated with bentonite to minimize seepage, or the pond should be lined with about two-inch thicknesses of cement concrete, preferably reinforced with wire mesh (about twenty gauge wire spaced two inches on centers) to prevent cracking. Bentonite is a colloidal clay which swells to many times its dry volume when wetted. It may either be well mixed with the upper layers of earth and then rolled tight before admitting water, or, preferably, a two-inch-thick layer should be placed, covered with six inches of earth, and then rolled or tamped firm. Artificial ponds should have drain plugs with outlets, so that they can be drained and cleaned if necessary.

Usually it will be possible to have the main breeding pond or ponds only in the country, possibly at a considerable distance from population centers. In that case it is desirable to have one or more distribution ponds strategically located in the population centers. These ponds may be built of concrete, about ten feet long, five feet wide, and two feet deep, and can usually be placed in a public park and fenced off, as people have a noticeable tendency to throw things into such ponds, which then become foul very quickly. The distribution ponds can be stocked as needed from the main breeding pond and drawn from as necessary for local distribution, thus saving the considerable expense of frequent long trips to the main breeding pond.

Under most circumstances we have found it unnecessary to feed the fish artificially. If feeding appears to be required, dog biscuit broken up into small pieces (but not granulated) has proved satisfactory. They will also take stale bread which is, however, deficient in protein and probably an insufficient food.

Breeding ponds should be protected from natural enemies, of which pelicans, cranes, and certain species of snakes seem to be the most destructive. A network of ordinary telephone wires spaced about three feet apart, and set about three feet above the water surface, will deter the birds from entering the pond; a fence of close-woven wire mesh (twelve wires to the inch) about eighteen inches high will keep out the snakes.

### Transporting and distributing gambusia

*Gambusia affinis* can be transported easily if certain precautions are taken. Preferably young, immature fish should be shipped, as they stand transportation better than mature fish. Gravid females do

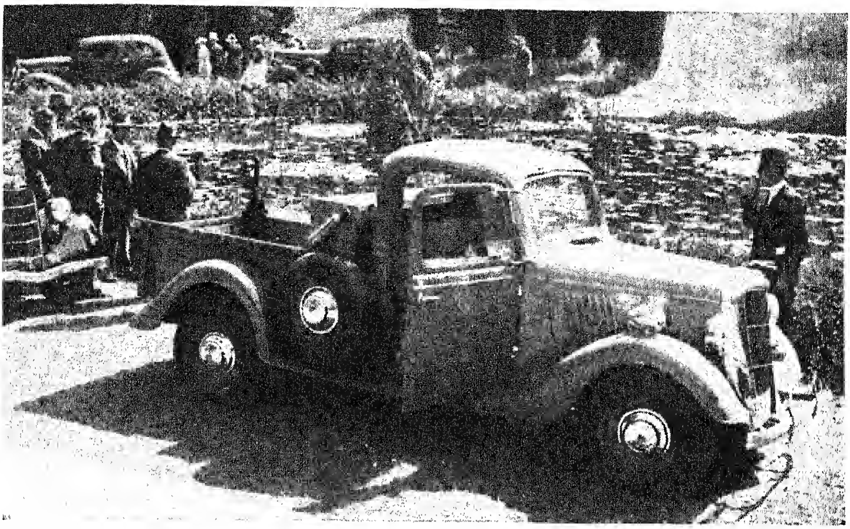

Figure 66. Breeding ponds for *Gambusia affinis,* on a private estate, being inspected by delegates to a mosquito abatement conference

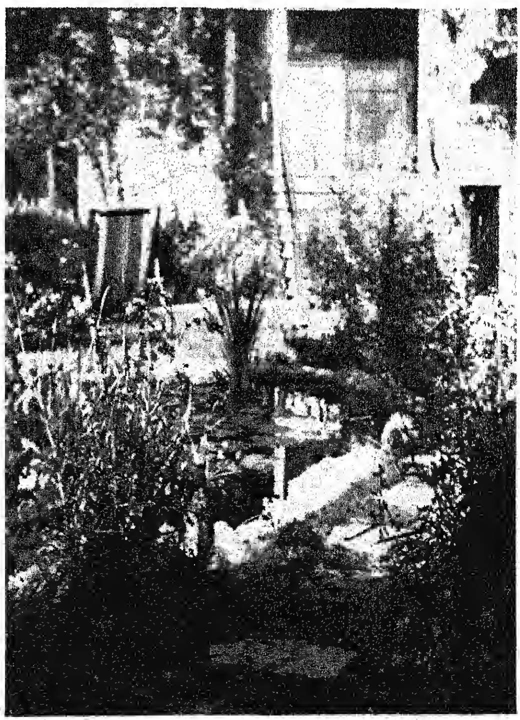

Figure 67. A garden lily pond is frequently a prolific mosquito breeder

not stand long distance transportation, and should be eliminated from any shipment. We have tried shipping gravid females on an overnight railroad journey, but have had nearly a 100 per cent loss in transit, whereas young fish under the same conditions came through with less than ten per cent loss.

If it becomes necessary to transport *Gambusia* in hot weather, the containers should be iced if possible or wrapped with wet burlap, and should be transported at night only. Ten-gallon milk cans make satisfactory shipping containers. The tops should be punched with many holes for air, and if possible the covers should be left off entirely during the journey. If carried by truck, this can be done. The water level in the cans should be kept below the point where the top of the can begins to narrow, in order to retain the maximum water-surface area. If carried by truck, stops at intervals of about an hour should be made, part of the water poured out, any dead fish removed, and fresh water added in a fine spray so as to furnish oxygen for the fish.

If these precautions are taken, about 300 fish per ten-gallon can may be safely transported by truck on one-night journeys in cool weather. For an hour's trip as many as 500 fish per ten-gallon can may be transported with a moderate loss. For journeys on trains, or for longer trips, not over 200 fish per can should be shipped, lessening the number according to length of the trip and the temperature.

For distribution on a mosquito abatement project (except for stocking large natural ponds or streams) fifty or a hundred small fish can be carried in a five-gallon wood barrel with a cover of bobbinet or other open cloth, and the fish withdrawn by a small kitchen strainer with handle. The cool wood barrel is preferred to a metal container, especially where the fish are constantly carried on the truck. For large stocking operations the ten-gallon cans are more satisfactory.

Where fish are a satisfactory tool in mosquito abatement work, we believe that the mosquito abatement project should breed and distribute free within its area as many *Gambusia* or appropriate larvicidal fish as may be required for mosquito control purposes. This may be done by a special man or by the regular foreman, according to local conditions and requirements. The fish should not be distributed indiscriminately without investigation. An employee should always take the fish to the place where they are wanted, and find out whether the fish are required and adapted to that place. Frequently it will be found that an abatement measure other than fish is needed. It is a fact that people will ask for fish under the impression that merely placing *Gambusia* in their garden pool will eliminate the mosquitoes which are annoying them but which are really bred elsewhere.

In recent years the ornamental garden pool has become a fad, and in many cases these pools are prolific breeders of *Culex pipiens*. In some towns as many as one place in four has some sort of pool. Unless stocked with fish, these pools will almost certainly breed mosquitoes. While our experience with *Gambusia* in garden pools has been quite satisfactory, we are informed that in Tennessee and Mississippi these fish have not been successful in controlling mosquito breeding in such pools. If there are heavy growths of algae, or if overhanging vines reach the water, control by *Gambusia* in garden pools may be poor. The Memphis health department, for example, considers the lily pond stocked with *Gambusia* to be a menace (personal communications from J. A. LePrince).

Frequently these ornamental ponds are stocked with goldfish (*Carassius auratus*), either the common type or one or more of the fancy varieties. We have found that goldfish usually will keep garden pools free from culicine mosquitoes, but they are not always successful, and their use is rather a gamble. The common tendency is to overfeed these fish, with the result that they become lethargic and have no ambition to consume mosquito larvae. Goldfish should probably not be considered as a means of *Anopheles* control.

It is advisable to warn persons who have goldfish in their ornamental ponds that the addition of *Gambusia* is unnecessary if the goldfish are not overfed, and that the *Gambusia* under some conditions will attack the goldfish and tear their fins. The presence of *Gambusia* at the spawning time for goldfish is also detrimental to any multiplication of the goldfish.

If an ornamental pool or a natural pond is found to be breeding mosquitoes profusely, it is advisable to kill off the crop of mosquito larvae before introducing the fish, or their progress in eating the larvae may be slow. For natural ponds the larvae can be killed with a distillate, or a kerosene; for ornamental garden pools, especially with water lilies or other aquatic plants, the distillates may do considerable damage. In this case we have found a light spray of pyrethrum extract effective in killing larvae and pupae, without damaging vegetation.

*Gambusia* can be used successfully for mosquito control in wells, cisterns, tanks for domestic water supply, barrels, and other clean, sharp-edged water containers. For this reason they can be used for the control of *Aedes aegypti* in regions where water for domestic purposes is collected or kept in barrels, ollas, or other vessels. The fish do not have any deleterious effect upon drinking water in such containers.

### Gambusia in Salt Water and Sewage

A. M. Emerick, superintendent of the Napa County, California, Mosquito Abatement District, has been quite successful in planting *Gambusia* in the brackish water of marshes adjacent to San Pablo Bay. We have found them thriving in ponds with relatively large amounts of calcium, magnesium, and sulphur at Byron Hot Springs, California.

If the fish are to be used in very salty or mineralized water, it would appear to be advisable to place them first in brackish water for about a week before putting them into the salt water.

Emerick has also adapted *Gambusia* so that they thrive in sewage ponds which are practically devoid of all dissolved oxygen. The large sewage ponds at Calistoga, California, which formerly were prolific mosquito breeders, have in recent years been kept under excellent control by means of *Gambusia affinis* which were gradually adapted to living and multiplying in municipal sewage.

### Limitations on the Use of Fish

Although *Gambusia,* as well as surface-feeding fish in general, have a useful place in mosquito control, it is necessary to recognize that they have limitations. In the first place, all natural control measures reach a balance at some point; complete extirpation of the victims will result in starvation and extinction of the predators. Nature seldom over-controls except for short periods in limited areas. The constant trend is toward the establishment of an equilibrium, sometimes precarious and easily upset, in the food supply of organisms living in the same environment.

It is possible that the success of *Gambusia* in controlling mosquito breeding upon introduction into new areas may be due in part at least to the sudden upset in ecological balance resulting from their introduction; after a period of years the balance may again be restored, in part at least. On the other hand, the recognized limitations of *Gambusia* in the warmer climates in America may be due in part to that balance having been already achieved. In the southeastern United States *Gambusia* have not been as successful in mosquito control as in Italy and in California. In the sloughs and bayous of the lower Mississippi Valley *Anopheles* and *Gambusia* exist together and both develop prolifically.

Against *Anopheles quadrimaculatus* surface-feeding fish are handicapped, as floatage protects the larvae from discovery and destruction. Considerable growth of algae, particularly *Spirogyra*, will also protect mosquito larvae, especially *Anopheles* larvae, from destruction by fish. We have seen T. H. G. Aitken take a very few *Anopheles maculipennis* larvae from a green algae mass in a *Gambusia* breeding pond in April; however, there was no evidence that any adults succeeded in emerging later.

Another difficulty with *Gambusia* is that in some areas their efficiency varies with the season. For example, J. A. LePrince informs us that N. H. Rector finds that *Gambusia* give excellent larval control in Mississippi in April, and poor control in August.

It is possible that *Gambusia* strains may vary in adaptability to transplantation. For example, T. J. Headlee reported that they failed to survive in southern New Jersey; but J. Lyle Clarke has successfully established them in the Des Plaines Valley in northern Illinois, a much colder climate; D. M. Rees has established them in Utah at about 5000 feet elevation; and A. M. Emerick has successfully planted them on Puget Sound near the Canadian border.

Recently Clarke[6] has indicated that about seventeen years ago *Gambusia* had been found to successfully survive the rigorous winters at Winnetka, Illinois, and this strain has been transplanted in the Des Plaines District and survived, whereas new importations into Illinois from Florida failed to survive the winter. It appears to be the opinion of ichthyologists who have investigated the matter that the Winnetka strain of fish is a mutant or "sport" which is adapted to survival under severe winter conditions.

Possibly *Gambusia* strains may vary in their larvicidal effectiveness, and perhaps breeding experiments could produce a more efficient strain. But we know of no investigations along this line. It is also possible that there are species of fish which could be introduced into regions where *Gambusia* has not proved to be effective, and which would do the job not done effectively by the *Gambusia*.

Caution, experimentation, and careful observation of results are necessary in the use of fish as a mosquito control measure. Above all, the press needs to be warned against a too enthusiastic advocacy of fish control, especially before the efficacy and limitations of this method of control in a particular area have been definitely established.

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# XIV

## SUPPLEMENTARY PROTECTIVE MEASURES

In addition to such primary mosquito abatement measures as naturalistic control and drainage, and the principal auxiliary measures such as oiling, larviciding, and the use of fish, there are several supplementary measures which can be used with more or less success according to local conditions. These measures are intended either to prevent access by adult mosquitoes to their human victims or to destroy mosquitoes which may have escaped the principal abatement measures. They have a place of definite value in any campaign against a mosquito-transmitted disease, but they should not be used as substitutes to primary attacks upon mosquito production points, except under unusual conditions.

### Screens

Adequate screens are an important adjunct in any campaign for eradication of mosquito-transmitted disease and are essential to ordinary comfort in tropical and semi-tropical climates, protecting the occupants of dwellings against the discomfort or even danger of the numerous insects of such areas.

Two problems are usually obvious in respect to screening. The more difficult of the two is the adequate screening of existing houses, especially of the poorer types. Many of these houses, particularly the average Negro shanty in the southern states, cannot be properly mosquito-proofed without some reconstruction or changes. On the other hand, there is the problem of proper construction of new houses to obtain maximum protection against insect invasion, with reasonable comfort in hot weather.

Four fundamental ideas must be kept in mind and applied in the case of screening: 1) the kind and size of screen must be suited to the exposure or climatic condition; 2) the screen must be protected or reinforced where necessary against mechanical breakage due to ordinary usage; 3) all apertures, except those effectively screened, must be closed so as to prevent access by insects; 4) ventilation with screening must be so good that the habitants will not prefer in warm weather to remain outdoors in the evening and at night.

The kind and size of screen to be used depend upon several factors. Screen wire must be strong enough to resist the mechanical injury that will occur in ordinary usage. The size of aperture between wires must be small enough to exclude the species of mosquitoes occurring locally. In some areas fourteen meshes or spaces per inch each way will be sufficient, but generally sixteen meshes per inch is the largest size that can be depended upon to exclude mosquitoes, and against *Aedes aegypti* and a few other small mosquitoes eighteen meshes per inch may be necessary.

In specifying screen material the best criterion is the effective size of opening between wires. This is governed by the number of wires per inch, and the diameter of the wires. An aperture size greater than 0.0475 inch cannot be depended upon to keep out all mosquitoes.

The standard size of wire used in screens has a diameter of 0.009 to 0.010 inch. Extra heavy wire has a diameter of 0.015 inch. Standard sixteen-mesh screen made with wire of 0.009 to 0.010 inch diameter has an aperture size of about 0.0512 inch, and does not exclude many *Aedes* and some *Anopheles* species. Extra heavy sixteen-mesh screen made with wire of 0.015 inch diameter has an aperture of 0.0475 inch. Standard eighteen-mesh screen made with wire of 0.009 to 0.010 inch diameter has an aperture of about 0.0456 inch.

In general, extra heavy sixteen-mesh screen is to be preferred to eighteen-mesh standard screen, as the difference in effective aperture size (about 0.0019 inch) is inappreciable, and the greater mechanical strength of the larger wire size renders such screen less liable to mechanical breakage, or to deterioration under adverse atmospheric conditions.

The present United States Army specifications call for a maximum aperture size of 0.0475 inch for wire screen, and not over 0.05 inch for stiff bobbinet. (Note: to exclude sand flies, *Phlebotomus sp.*, the maximum aperture size should be 0.0334 inch.)

Several types of wire screen are available.[1] Steel wire cloth may be either painted or electrogalvanized. In the painted screen the fabric is run through a bath of paint after weaving, the surplus paint blown off, and the painted fabric dried in a heated tower before reeling up into commercial rolls. The effectiveness of the paint coating depends primarily on the quality of the paint used, but care in preparing the wire for painting (clean, bright wire is necessary for a satisfactory paint film), the amount of paint film, and the method of application are also important factors. The paint must be adherent to metal, must retain considerable flexibility for a long period, and must be resistant to weathering. The use of painted screen cannot be recommended.

In electrogalvanizing, the wire cloth is run through a galvanizing bath with zinc electrodes. The action of the electric current causes zinc to pass from the electrodes and be deposited as a thin layer of chemically pure zinc upon the wire cloth. The care with which the galvanizing process is carried out is highly important in obtaining a good quality of screen, as the zinc deposit must be very fine in grain and thoroughly adherent to the wire. Coarse grain galvanizing rapidly done on poorly prepared wire may look as well as fine grain galvanizing on well prepared wire, but will be considerably less rust resistant.

Screen made of pre-galvanized wire is not recommended, as the bending and scraping in the process of weaving cause minute cracks in the zinc coating on the wire and some flaking, so that the wire is very apt to rust, particularly at the intersections.

Pure copper wire is used for screens but it may be soft and lacking in resilience so that it is easily damaged mechanically. In the Panama Canal Zone[2] screen made from hard-drawn wire, 99.8 per cent copper, 0.015 inch in diameter, sixteen meshes to the inch, has proved to be most satisfactory in comparison with other screen materials. A good screen is a bronze cloth made from a ninety per cent copper–ten per cent tin wire which is resistant to corrosion and more resilient and stronger than pure copper. A cloth made from manganese-bronze wire should be mechanically strong and very resistant to corrosion, but we have not seen it used for this purpose. Monel metal, a nickel-cobalt alloy, can also be obtained in screens but its comparatively excessive cost makes its use impractical except in cases of unusually severe exposure. The most promising outlook in wire screen materials would appear to be in some of the so-called stainless steels, provided these can be produced at a reasonable cost.

For most conditions, a good grade of electrogalvanized screen will prove satisfactory. Earle[3] in Porto Rico, where the exposure is rather severe, found galvanized wire cloth satisfactory in the interior of the island but found that bronze screen was required near the sea-coast. Bronze wire under severe sea-coast exposure will corrode and should be painted with a transparent flexible enamel of the type used for insulation of electrical wires or with a good grade of spar varnish, in order to obtain maximum life in such situations.

Wire screen is usually sold wholesale in rolls 100 feet in length, and in standard widths from eighteen to forty-eight inches, increasing by two inches for each size.

Insect-proof screen, no matter what metal it is made of, cannot withstand rough handling, and is subject to breakage as well as to deterioration. Mechanical breakage is an important matter especially on doors, which should be protected at the points where breakage is most apt to occur. Two places receive the hardest usage: the lower outer corner where the foot is applied in kicking the door open; and the middle edge in the region of the latch. These two places should be reinforced with wood or sheet metal. It is also desirable to use screwed metal corner plates to reinforce the door corners, and a diagonal rod to prevent sag. Doors made of laminated wood or five-ply plywood, prepared with waterproof synthetic adhesives, are less apt to warp than doors made of plain lumber. All joints should be painted with one coat white lead in raw linseed oil before joining (except when glued joints are used).

As window screens are not so likely to be subjected to mechanical injury, special protection is not usually required. The wood frame should be strongly constructed, preferably of laminated wood to prevent warping.

It is obvious that the wood frames of both door and window screens should be well painted, preferably with a priming coat of white lead in raw linseed oil after the frames are complete and before applying the screen, followed by one or two coats of a good grade of outside paint in selected color after the screen is applied. In Panama it has been found that paints containing zinc set up a reaction with copper screen, causing the screen to split at contacts with zinc-painted wood trim. Therefore only lead base paints should be used on trim in contact with copper screen. For a similar reason galvanized nails should not be used in contact with copper screen nor should galvanized protective screen be allowed to come in contact with copper screen.

The screens should be attached to the frames by being stretched tightly and well tacked down before applying the covering strips. The latter must be well nailed. Cover strips may be one-half inch half-round if desired but preferably for greater strength should be about one by one-fourth inch flats.

The method of fitting screen doors and window screens is just as important as the screen itself. Too frequently a well made screen is perfectly useless because insects can pass freely around the edges of the frame. In order to insect-proof the screens, stops must be nailed around the inside of the door or window casing so that when closed the frames fit tightly in their casings. Windows can be screened by tacking screen on the outside of the window casing and then applying strips along the screen edges. This is the cheapest method of screening windows but has the serious objection that the screen is not removable.

In addition to screening doors and windows it is important to close all other openings in the house effectively, so that there is no aperture, however small, through which insects may enter. In an existing dwelling this requires a careful inspection of the house to locate cracks, crevices, knotholes, and the like, in floors, walls, and ceilings. In the poorer class of dwellings, having unlined walls or ceilings, such small openings may be numerous. Holes especially in floors are best protected by nailing sheet metal over them. So-called "tin" shingles which may be obtained in bundles of 100, painted with one coat of red lead, are very useful for this purpose but, if necessary, ordinary tin cans, if clean and not rusted, can be cut with metal snips, flattened out, and used for the same purpose. For long separation cracks between boards, flat battens approximately two by three-eighths inches, preferably painted with one coat of white lead in raw linseed oil before applying, can be nailed over the cracks. For separation cracks in corners, quarter-round wood one-half inch or larger, or square fillers one-half inch or larger as required, may be nailed in to cover the cracks.

Chimneys and other vent flues should also be screened during the mosquito season, but the screens should be removed from chimneys when winter comes and the fireplaces or stoves are used frequently or steadily, as the smoke rapidly corrodes any kind of screen material.

Screening which materially interferes with ventilation in warm or hot climates will defeat its purpose, as the occupants of such a house will either remove the screens or remove themselves outdoors in the evening. The most useful part of a screened house in a warm climate is a large screened porch located preferably on the north-easterly side of the house (in the northern hemisphere), so that it will be on the shady side from noon until sunset. Except for a base board about twelve inches high and the necessary supporting timbers, the walls of the screened porch should be all screen to obtain the maximum ventilation possible. Also, if possible, the porch should have screen on three sides, so as to permit any available breeze to create air currents in the porch. The size of the porch should be the maximum reasonably possible within the means available. In general, twelve feet long and seven feet wide with a minimum height to the roof of eight feet, should be considered as the least dimensions for a screened porch. It is desirable also to have the porch roof overhang from eighteen inches to two feet for greater shade. Existing houses or cabins as a rule can have screened porches built on to them, with a resulting great increase in the comfort of the occupants.

In tropical regions and in areas in the temperate zone where a severe mosquito infestation exists, it is practically essential that screened vestibules be provided at all entrances to habitations. The vestibule may be small, say five feet long by four feet wide, and should be provided with an outside screened door having an automatic spring to close it. A small sprayer with pyrethrum spray kept in the vestibule can be used to kill any insects carried on the person into the vestibule before entering the building.

It is entirely possible to build mosquito-proof houses in tropical and semi-tropical regions at a cost but slightly greater than unscreened houses. More care must be taken to avoid minor openings, such as knotholes, cracks in plaster, or separation between boards; and adequate screens must be provided. Lumber should be first grade, well seasoned, straight grained, and free from large knots, checks, pitch pockets, and shrinkage cracks. Exterior boarding should be tongue-and-groove, lapped, or splined. Flooring should be tongue-and-groove. Door and window casing should be carefully framed and set so that there will be no possibility of separation cracks through which mosquitoes may gain access to the interior of the house.

The Tennessee department of public health[4, 5, 6, 7, 8, 9] has done an excellent piece of work in preparing standard plans and specifications for farm tenant houses which are inexpensive and yet well designed and are mosquito-proof if given reasonable maintenance. As most of the difficulties in mosquito-proofing occur in the homes of the poorer farm tenants and farm laborers, these designs are good illustrations of the fact that satisfactory housing need not be expensive housing.

In hot climates, intelligent use should be made of available native building materials. Thick (three feet) exterior walls of native stone, or of adobe brick stabilized by mixing with 5 per cent emulsified asphalt, can produce a cool house, provided a double roof with ventilating ridge louvres is constructed. Exterior walls on the sunny side of the house should be protected from direct rays of the sun by verandahs ten to fifteen feet wide. Heat-reflecting materials such as aluminum foil or aluminum paint will also appreciably reduce interior temperatures. Room heights must be much greater than in temperate climates, and if punkahs are to be swung from the ceiling, heights of about sixteen feet may be advisable.

The essential point in tropical housing is to provide cool, well-ventilated, screened houses, so that the occupants will not be tempted to go outside to cool off. The white man going to the tropics usually has to unlearn practically everything he thinks he knows about housing before he can be both comfortable and properly protected.

In the final analysis, the value of screening is dependent upon the care with which it is maintained and on personal equations in the people protected. Even exceptional efforts to prevent malarial infection by making screening as thorough as possible (as at the Panama Canal Zone in 1937) may be found to be only partially effective, since people can be infected outside the screened quarters.

A supplementary measure which is always useful in that it tends to discourage mosquito prevalence to a considerable extent is the removal of dense shrubbery and vines from the immediate vicinity of houses, so as to reduce to a minimum the available day-time harborage of the pests. Accompanying this measure should also be the reduction to a minimum of garden and lawn watering, and the performance of such work in the morning, not in the evening, so that there will be a minimum of humidity about the house during the evening hours. These measures, while they will not eliminate mosquitoes, will in many cases, especially in hot, dry climates, make a noticeable difference in the numbers of mosquitoes about a house and will contribute to the comfort of the occupants.

### Bed nets

Sleeping outdoors in regions where mosquitoes are prevalent requires an effective bed net for reasonable comfort or protection from infection. Bed nets are also useful when it is necessary to sleep in unscreened houses in mosquito-infested regions. They should be of sufficient size to hang well away from the bed, so that no portion of the body will be likely to touch the net during sleep. The top of the net should be at least three feet above the bed. A light collapsible framework to support the bed net is desirable. The net should be reinforced with cloth at all edges and corners, and strongly sewed, and the skirt should be long enough to fall on the ground or floor with several inches to spare, or to be adequately tucked in under the mattress.

For sleeping on the ground, a bed net nine feet long and five feet wide, with sides about five and one-half feet high, will give sufficient space for comfort. If a folding cot is used, the length of the sides should be increased about a foot. Extra netting, and needles and thread, should be carried to make repairs of the rents and holes which will surely occur. Adhesive tape is also useful for repairing bed nets. Bed net material should preferably be a stiff bobbinet with effective apertures not over 0.05 inch.

### Mosquito repellents

Numerous substances have been used as mosquito repellents in regions of severe infestations. Few of them were of any appreciable effect, and none could be depended upon for more than a short time. Most of them were mixtures of oil of citronella with various added ingredients such as camphor, eucalyptus oil, tar, oil of cedar, or carbolic acid.

Recent research[10] by the United States Department of Agriculture and others has developed three new and fairly effective mosquito repellents which can be applied to the skin. Dimethyl phthalate is the material most effective against *Anopheles* species, and 2-ethyl-3-hexanedinol ("612") is the material most effective against *Culex* species. A third material, indalone, is reported to be quite effective against salt-marsh *Aedes* species. These materials are liquids which are applied to the exposed skin surfaces and to those parts of the clothing which may be stretched tight against the skin (knees, buttocks, shoulders). Dimethyl phthalate and "612" are effective for as long as four hours under sweating conditions, and for about twice as long if not sweating profusely.

These new repellents are of very great value in protecting military personnel against infection with mosquito-transmitted diseases while under combat conditions and on night sentry duty, and will also be of value in protecting civilians, such as construction crews, hunters, fishermen, and campers in areas where there is a severe mosquito infestation.

Various repellent sprays applied to the environment have been used to discourage mosquito attacks. Ginsburg[11] reports on a number of tests using the New Jersey larvicide (pyrethrum-kerosene emulsion), as a repellent in limited areas for a short period of time. Using various dilutions of the larvicide (from a concentrated solution down to dilution of one to twelve), appreciable relief has been obtained at outdoor gatherings such as lawn parties, picnics, and the like. Several of the New Jersey districts provide a spraying service for outdoor gatherings, charging the approximate cost. The results are apparently satisfactory. The spray is applied just before the beginning of the function. High pressures (at least 400 pounds per square inch) and good atomizing nozzles are necessary, and the adjacent area in the windward direction should be sprayed, as well as the immediate area to be protected. Approximately fifty gallons per acre of 1 to 10 dilution is used. It should be "fogged" well up into the air so as to cover all vegetation, including trees.

It is probable that under tropical conditions the use of this spraying technique will not only result in greater comfort, but may kill off mosquito breeding in trees and plants near the protected area, and may help to reduce the incidence of mosquito-transmitted disease.

The United States Public Health Service has tried a number of materials for outdoor repellent spraying, and as of December 10, 1943 (personal communication from F. L. Knowles, Senior Biophysicist, Memphis, Tennessee), has found that an emulsion of thanite gives the best results. The stock thanite emulsion used was made according to the following formula:

| | |
|---|---|
| Thanite | 55% |
| Kerosene | 15% |
| B 1956 Emulsifier | 10% |
| Water | 20% |

For spraying, this stock emulsion was diluted in the ratio of one part of stock to thirteen parts water.

Against *Anopheles quadrimaculatus* and *Psorophora confinnis* very good protection was obtained, but against salt-marsh mosquitoes only about 50 per cent protection was obtained during the period of greatest biting intensity.

### Killing adult mosquitoes

Numerous sprays for killing adult mosquitoes are marketed under various trade names. Practically all of them are simply pyrethrum flowers extracted in a petroleum solvent such as cleaner's solvent or a refined kerosene. The normal quantity of active ingredient is the pyrethrum extracted from one to three pounds of the flowers per gallon of solvent.

When any appreciable amount of such spray is to be used, it is generally more economical to buy the extract as such, on a specification calling for a definite percentage (by weight) of pyrethrin per gallon of a specified solvent. Another method is to buy the standardized pyrethrin concentrate (such as Pyrocide 20) and the solvent separately, and make up the spray material as required. A small amount of any pleasant aromatic oil can be added to mask the odor of the petroleum solvent.

Petroleum solvent–pyrethrum sprays, if adequately toxic, are useful in killing adult mosquitoes within houses. The room being sprayed should be kept closed for one-half hour if possible so that the fumes will have opportunity to kill all mosquitoes in it, but mosquitoes can be successfully killed even in thatched native huts if thorough spraying is done. With reasonably effective pyrethrum extract sprays available, it seems to be a waste of time and effort to attempt to catch or kill mosquitoes in houses by using swatters or other devices. However, if effective sprays are not obtainable, or if for some reason it is not possible to use them, it would appear to be a useful procedure in malarial regions to take considerable pains to kill all mosquitoes which do succeed in getting past the screens and into houses. During the day they will be found harboring in protected places such as closets and behind picture frames. The skillful use of an ordinary fly-swatter will kill most if not all such mosquitoes. Such a method, however, is obviously one that usually cannot be performed by official mosquito abatement agencies, but must be left to the individual householder.

Gorgas used the daily catching of engorged *Anopheles* females in tents near Miraflores Locks as a means of malaria control, and succeeded in keeping the malaria rate down to four per cent per month, which was the normal rate at that time (1908) for workmen sleeping in screened quarters at camps where mosquito control work was practiced. In the same year at Diablo Hill, three miles from Panama, one Negro boy was employed about one hour a day in catching adult mosquitoes in the bunk cars of a railroad camp at the edge of a prolific *Anopheles* breeding swamp. The malaria sick-rate among these laborers was one forty-second of the malaria sick-rate among the United States Marines quartered in a near-by well-screened barracks on a hill top.[12]

Thorough application of pyrethrum sprays to kill adult mosquitoes will result in a very appreciable reduction in mosquito-transmitted disease. The basic idea, of course, is to prevent any one mosquito from getting in more than one bite, as she must first bite an infected person before becoming infected herself. Therefore in the tropics the regular spraying of the native quarters will be about as important in an adult mosquito destruction campaign as will be the spraying of the quarters to be protected.

Russell and Knipe,[13] De Meillon,[14] and Park Ross[15] have demonstrated the disease-preventing effectiveness of adequate spraying methods. Russell and Knipe[16] finally were able to report that by improved techniques and equipment malaria could be greatly reduced in Indian villages by once-a-week spraying of native houses with a mixture of one part Pyrocide 20 to nineteen parts kerosene, at a cost within the means of the villagers. Park Ross found in South Africa that definite reductions in malaria incidence could be obtained by thorough spraying to kill the vectors, *Anopheles gambiae* and *Anopheles funestus*.

Soper and Wilson[17] in Brazil used the following spray: five parts of Pyrocide 20 (containing two grams of pyrethrin in each 10 cc.), ten parts of carbon tetrachloride, and eighty-five parts of kerosene or diesel oil. The carbon tetrachloride was added to minimize the fire hazard. The equipment used was a De Vilbiss type spray pistol with an air compressor; for hand spraying by single operators fifteen to twenty pounds air pressure was furnished from a cylinder sprayer; in towns a power-driven compressor mounted on a cart furnished air at thirty-five to forty pounds pressure for several pistols simultaneously. Houses were sprayed weekly, as an adjunct to the anti-larval campaign against *Anopheles gambiae.* Houses were kept closed for ten minutes after spraying.

A recent valuable development in spraying methods has been the aerosol cylinders,[18] which dispense pyrethrin in the finely divided form of an aerosol which is highly toxic to adult mosquitoes, especially in closed quarters. The spray mixture generally used is about one per cent pyrethrin, 2 to 4 per cent sesame oil as an activator of the pyrethrin, and 97 to 95 per cent of Freon (dichloro-difluoromethane). The Freon maintains its vapor pressure until the cylinder content is discharged. At present these cylinders are available only for military use.

In addition to disinsecticizing houses and barracks, the Freon-pyrethrum cylinders are of value in military campaigns for killing and deterring mosquitoes in forward positions such as fox-holes, gun emplacements, pill boxes, shelters, and the like.

Attention should also be called to the effect of dichloro-diphenyl-trichloroethane (DDT or Gesarol) in killing adult mosquitoes which alight upon surfaces sprayed with this insecticide. Dissolved in an appropriate solvent and sprayed on walls and ceilings, it remains effective for several weeks, all mosquitoes resting upon the sprayed surfaces dying after a few minutes' contact. In tropical regions this spray should prove to be of very great value not only against mosquitoes, but probably against a number of insects which are pests.

When an epidemic of any mosquito-transmitted disease occurs, spraying to kill adult mosquitoes would be definitely indicated. Used as the sole method of control it has appreciable value in limited areas. In an intensive campaign for the extirpation of a species it is also of real value as an adjunct to anti-larval methods, when dealing with comparatively domestic species such as *Aedes aegypti* and *Anopheles gambiae.*

### Natural enemies of adult mosquitoes

Several years ago bats were enthusiastically promoted as a means of destroying mosquitoes. Unfortunately, municipal bat roosts and bat culture did not seem to work out as effectively as the proponents had hoped. Today little is heard about them as a mosquito abatement weapon. In fact, there seems to be some probability that the mosquitoes feed on the bats, as well as that the bats feed on the mosquitoes. Doubtless bats do eat numbers of mosquitoes, as well as other insects, but there is little or no evidence to show that they are a factor of any appreciable value in mosquito control. This is probably true also of whip-poor-wills, night hawks, and other crepuscular insectivorous birds.

### Diverting mosquitoes from humans to animals

A measure which has a certain amount of usefulness in reducing the tendency to attack by mosquitoes is to place the barns or quarters of any domestic animals, particularly horses and cattle, between the house and the known mosquito breeding areas. There will be a tendency for the mosquitoes in migrating from their breeding places to fill up on the blood of these animals, especially if the mosquitoes are zoophilous in their tastes, and to be little inclined to proceed further to the house and attack humans. This procedure is apparently well worth trying where farm animals are available.

In the control of malaria the presence of farm animals may have a marked effect in minimizing human malaria, where zoophilous types of *Anopheles* are the principal species. Some of the great outbreaks of malaria after the World War (for instance in Russia) may have been in part attributable to the economic disruption which resulted in a scarcity of farm animals, causing zoophilous anophelines of necessity to resort to humans for blood meals.

## *MOSQUITOES AND AEROPLANES*

The transportation of mosquitoes by aeroplanes, either by regular transport planes on tropical routes or between tropical and temperate climate areas, or by military planes on wide ranging campaigns, has become a matter of concern to both civilian and military authorities. The possibility of introducing either a new vector species into a hitherto uninfested region or an infected vector into a previously uninfected area has been greatly increased by the rapidity of air transport; and the public health implications in the problem are of considerable importance.

Certain types of mosquitoes have been introduced into isolated islands (for example, Hawaiian Islands) by slow moving sailing ships, under conditions where continuous breeding during transportation was possible. But with aeroplanes, only a few hours or days being required for extensive trips, the introduction of a species into a new region is a much greater possibility. The transport, by either a commercial or military aeroplane, of a fertilized *Anopheles maculipennis* female from California to the Hawaiian Islands, where malaria is unknown, might ultimately become both a public health and an economic disaster to the Islands. The transport of an infected *Aedes aegypti* female from a South American airport to one of the southern cities in the United States might start an epidemic of yellow fever.

The searching of aeroplanes for mosquitoes has shown that transport of mosquitoes actually does occur. Symes,[19] at Kisumu and Nairobi in Africa, searching 196 aeroplanes arriving from Sudan and Tanganyika, found seventy-two *Anopheles* and eighty-five *Culex*. A live *Culiseta incidens* male, transported from Alameda to Honolulu on the Clipper trip of August 4, 1937,[20] produced a mild furor among the Island health authorities when it was at first erroneously identified as an *Anopheles* mosquito. Griffitts[21] found one male *Aedes aegypti* and twenty-eight culicines on 102 planes arriving at Miami. On the other hand, Hicks and Chand[22] failed to catch any mosquitoes in 106 planes arriving at Karachi Air Port (India). However, on experimental lots shipped in cages to Amsterdam and return (about 9000 miles in six days) there were two survivors out of thirty-six. Griffitts[23] liberated stained *A. aegypti* in aeroplanes at San Salvador and recovered eight per cent alive after thirty hours on arrival at Brownsville; from San Salvador to Miami (eighty hours, three night stops) six per cent survived. From Cristobal to Brownsville, a trip requiring fifty-five hours with two night stops, 1610 *Aedes aegypti* were used on thirty trips and a two per cent recovery made on arrival. On a ten-hour journey from San Juan to Miami[21] about ten per cent of stained *A. aegypti* were recovered on arrival.

It was reported by da Silva[24] that between October 4, 1941, and

March 31, 1942, over 90 per cent of the aeroplanes from Africa arriving in Brazil carried arthropods, among them being *Anopheles gambiae*, *Aedes aegypti*, and *Glossina palpalis*, the latter being the tsetse fly which transmits trypanosomiasis (African sleeping sickness).

Hicks and Chand[22] performed experiments which indicate that rapid changes in altitude have little if any effect upon mosquitoes, but that changes in humidity may have an appreciable effect, aridity increasing the mortality. They studied the effect of pyrethrum extracts in killing mosquitoes in aeroplanes, and found it to be directly proportional to the amount of pyrethrins in the spray especially for mosquitoes in places (for example, under seats) into which a direct spray cannot easily be shot. They advise the use of pressure atomizers of the type used in paint spraying, as the hand sprayers are less uniform in application and are apt to spill large drops. An increase in contact time to fifteen minutes under closed conditions gives an increased percentage of kill.

There are several objections to the use of petroleum solvent pyrethrum sprays for disinsecticizing aeroplanes. A high flash point petroleum solvent may ultimately increase the fire hazard in fabrics as well as cause an oily film on metal surfaces, while a low flash point solvent increases the fire or even explosion hazard at the time of application. Non-inflammable solvents such as carbon tetrachloride may introduce toxic hazards to passengers. Methyl alcohol, another common solvent for pyrethrum, also has disadvantageous toxic properties. There is some possibility that high concentrations of pyrethrins may have some toxic effects on pilots and passengers. Imperial Airways succeeded in obtaining satisfactory results with an aqueous pyrethrum spray. The best spray at present available for this service appears to be the Freon-pyrethrum aerosol in pressure cylinders. It would be advisable, also, to experiment with dichloro-diphenyl-trichloroethane as a semi-permanent disinsecticizing agent.

On some air routes (for instance, from California to Hawaii) planes and passengers have been sprayed en route, which would appear to have certain dangerous aspects as well as being decidedly annoying to passengers. In general, it appears to be desirable to minimize the amount of spraying, which can be effected by the application of a number of procedures, as follows:

1. The airport area and a zone of at least one-half mile radius about the port should be kept under an intensive and effective program for the prevention or abatement of mosquito breeding.

2. Passengers in mosquito areas should leave and enter planes by means of a special screened, double door embarkation vestibule temporarily attached to the plane.

3. Aeroplanes should be mosquito proofed to the greatest extent possible. Ventilator openings should be screened, and other apertures closed. Protected areas within the plane, in or under which mosquitoes may hide, should be eliminated or reduced to a minimum. Seams, pockets, or depressed places on exterior surfaces of wings or fuselage, in which adult mosquitoes can adhere during flight, should also be eliminated.

4. In mosquito areas, planes removed from hangars to be placed on flights should be sprayed thoroughly with an effective spray, and held under tightly closed conditions for fifteen minutes before admitting passengers, crew, or load. Baggage and mail compartments should be sprayed after loading.

5. In tropical regions, effective sprays or aerosols should be used to destroy adult mosquitoes in airport structures, as a supplement to measures for the prevention of mosquito breeding.

6. Inspection services should be maintained at air fields for all aeroplanes arriving from areas from which important foreign species may be transported.

The problem of protecting flying and ground crew personnel at stations along air routes through tropical regions has been interestingly told by Coggeshall.[25] Whatever was possible to control *Anopheles gambiae* at these stations was done. At first bed nets had to be used, plus protective clothing; as quarters were built they were carefully screened, and spraying of quarters daily, or even twice daily, was carried on. Particular attention was paid to spraying native quarters, and wherever possible native quarters were moved one-half mile or more away from stations.

Discovered *Anopheles* breeding places were either treated with Paris green or oiled, and as soon as it could be attended to, drainage for mosquito breeding areas was installed. Maintenance crews were required to make the drains continuously effective.

Quinine and atebrine were used, but comparisons at different stations showed definitely that the mosquito control and protective measures were far more effective than drugs in preventing malaria, and in addition contributed greatly to comfort and morale.

In screening, eighteen-mesh bronze or monel metal cloth was used, and a maintenance man was required to keep the screening constantly in effective condition.

After these measures were in full effect mosquitoes were reduced almost to the vanishing point, even in the unscreened native compounds. The malaria incidence was reduced to only four cases in about 1600 men in September and October, 1942, at one station (Accra), whereas about 40 per cent morbidity had occurred in the previous season.

## *MOSQUITO CONTROL UNDER MILITARY ENVIRONMENT*

The practice of environmental mosquito control as it affects fixed military installations (mass protection) does not differ materially from such practice under civil conditions. Control operations applicable to field conditions, however, require a high degree of protection of the individual. In either case, control measures must be integrated with Army or Navy practice and conform to the military point of view. Dunham[26] points out that military sanitation, which comprehends mosquito control, calls for knowledge of the organization, operation, and general mission of the military establishment.

Responsibility for mosquito control in the United States Army is vested in the Commanding Officer, who depends on Medical and Sanitary Corps officers (under direction of the Surgeon) for mosquito surveys, recommendations, and supervision, on Quartermaster and Engineer Corps officers for supplies, equipment, and labor, and commonly on Engineer Corps officers for prosecution of environmental control measures.

Army Regulations No. 40–205 pertaining to Military Hygiene and Sanitation reads:

> The surgeon of each station or command is responsible for investigating the prevalence, distribution, and significant habits of those mosquitoes which may be transmitting disease to the troops or affecting their efficiency, morale or comfort.

Training Circular No. 108 (W.D., Sept. 21, 1943) states (Sec. 2):

> Responsibility for malaria control.—It is the responsibility of the unit commander to control malaria within his unit and his unit area. (See AR 40–205 and 40–210.) It is the responsibility of organization surgeons to survey the

malaria problem, to recommend measures needed for control, and to exercise technical supervision over control measures (see AR 40–205 and 40–210). The Corps of Engineers is charged with the responsibility of mosquito control work on real property (AR 100–80), and hence will carry out large scale programs of drainage, filling, and oiling.

Dunham[26] further points out that in many instances, because of the technical nature of such procedures, the Medical Department exercises direct and immediate supervision over all anti-mosquito work. Numerous highly trained and thoroughly equipped units have been activated within the Medical Department of the Army and the Navy during World War II for purposes of malaria-mosquito control.

Although no comparable units were in existence during World War I, it is of interest to note that one of us (Herms[27]) organized and operated a "malaria drainage detachment" at that time under the authority of the Surgeon, Port of Embarkation, Newport News, Virginia. This detachment consisted of about 300 Negro enlisted Sanitary and Hospital Corps men and stevedores under the immediate command of seven white Medical and Sanitary Corps officers. Twelve white Hospital Corps men were used as non-commissioned officers and inspectors. The commissioned personnel on field duty consisted of an experienced civil engineer, several physicians, and an entomologist well trained and experienced in medical entomology and parasitology.

The detachment was broken up into smaller units which were located in the principal camps, each unit with its own mess and canteen. Small emergency details were dispatched for malaria drainage duty at outlying stations when needed. Proper coordination and general supervision of the various units and detachments were maintained through the officer in charge of malarial drainage operations attached to the Office of the Port Surgeon at headquarters. In addition to the usual drainage operations, an educational program was carried out particularly to impress line officers and their men with the importance of mosquito control as it relates to the prevention of malaria and other mosquito-borne diseases. Emphasis was placed on the personal responsibility of the individual to protect himself against mosquito bites by applying mosquito repellents to hands and wrists and by wearing head nets when operating at night in hyperendemic areas where larvicidal methods were not practical. The daily collection and destruction of adult mosquitoes in tents and barracks were stressed, and a maintenance man was required to keep the screening constantly in effective condition.

After these measures were in full effect mosquitoes were reduced almost to the vanishing point, even in the unscreened native compounds. The malaria incidence was reduced to only four cases in about 1600 men in September and October, 1942, at one station (Accra), whereas about 40 per cent morbidity had occurred in the previous season.

### *MOSQUITO CONTROL UNDER MILITARY ENVIRONMENT*

The practice of environmental mosquito control as it affects fixed military installations (mass protection) does not differ materially from such practice under civil conditions. Control operations applicable to field conditions, however, require a high degree of protection of the individual. In either case, control measures must be integrated with Army or Navy practice and conform to the military point of view. Dunham[26] points out that military sanitation, which comprehends mosquito control, calls for knowledge of the organization, operation, and general mission of the military establishment.

Responsibility for mosquito control in the United States Army is vested in the Commanding Officer, who depends on Medical and Sanitary Corps officers (under direction of the Surgeon) for mosquito surveys, recommendations, and supervision, on Quartermaster and Engineer Corps officers for supplies, equipment, and labor, and commonly on Engineer Corps officers for prosecution of environmental control measures.

Army Regulations No. 40–205 pertaining to Military Hygiene and Sanitation reads:

> The surgeon of each station or command is responsible for investigating the prevalence, distribution, and significant habits of those mosquitoes which may be transmitting disease to the troops or affecting their efficiency, morale or comfort.

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The value of commercial fly sprays (pyrethrum extract in kerosene) in the destruction of adult mosquitoes was pointed out by Schneider[29] in 1937. He advised spraying daily at eight o'clock at night and early in the morning, "paying especial attention to dark corners, latrines, behind and under toilet fixtures, etc. Spray also under the eaves, about doors, and twice a week agitate the clothes which in these barracks are hung on a rack suspended from the ceiling, so that any mosquitoes which may have hidden there may be destroyed."

Simmons[30] (Chief, Preventive Medicine Service, Office of the Surgeon General, United States Army) points out that the dispatch of American troops to fight in tropical regions all over the world has restored malaria to its former position as one of the Army's most important disease hazards. He states, "Only by the determined efforts of thoroughly trained officers can we hope to outwit and outfight the mosquito vectors of this disease." As is so well put by Russell[31] (Chief, Tropical Disease Control Section, Office of the Surgeon General, U.S. Army), "The day of the amateur malariologist has passed. Malaria control is no longer simply pouring of oil or of quinine pills from bottles. . . . Constant attention is required to so many great and small details relating to entomology, parasitology, civil engineering, and medicine, that successful malaria control is rarely possible by part time or casual treatment."

These assertions by high medico-military authorities are supported by facts gleaned from the history of World War I: in Macedonia alone 80 per cent of 120,000 French troops were hospitalized because of malaria; in the spring of 1918, 25,000 British soldiers were sent home from Macedonia with chronic malaria. In fact whole armies, British, French, and German, were rendered immobile for three years in Macedonia, due to neglect or inability to control *Anopheles superpictus*, the vector in that area. In the early stages of the New Guinea and Solomon Islands campaigns of World War II the disability rates due to malaria were very high. With our present organization and methods for malaria control it should be possible for our military forces to operate hereafter in regions where malaria and other mosquito-borne diseases occur, with a minimum of disability from such causes.

### Organization for malaria control

World War II saw the organization of malaria survey units and malaria control units under the immediate administration of malariologists directly supervised by the Surgeon. Assistant malariologists aid in making parasite, spleen, and mosquito surveys and in planning control measures, and are particularly concerned with malaria discipline among the troops. The personnel of the malaria survey units should include competent medical entomologists and parasitologists, while the control units should include engineers familiar with mosquito control operations and having adequate knowledge of appropriate larvicides and other chemicals.

*Malaria survey units* have the following functions among others: 1) making surveys of mosquitoes (adults and larvae) in order to determine the species, their incidence, seasonal distribution, biology, and relation to malaria; 2) making malaria parasite surveys among troops and civilians as required; 3) keeping suitable records and spot maps; 4) making recommendations as to specific situations requiring mosquito control; 5) checking on the effectiveness of abatement measures applied by control units.

*Malaria control units* are responsible for planning, carrying out, and supervising malaria-mosquito control measures in all phases. It would seem appropriate to detail two to four men in every individual company (or other similar unit) to carry out such anti-malaria measures as pertain to the housekeeping of the unit.

*The survey.* Effective mosquito control cannot be achieved unless the breeding places, flight habits, biting habits, and disease-carrying potentialities of the various species indigenous to a given area are known. Such surveys, according to Russell,[31] may be of two types: 1) reconnaissance and 2) basic. The difference between the two types is in the degree of thoroughness with which they are carried out. For reasons of military urgency it is frequently not possible to make more than a reconnaissance survey, but in base camps and at shore stations it is usually possible and advisable to make a detailed basic survey. In either case, in any area surveyed every type of mosquito-breeding place should be sampled by the use of dippers or other devices, and the larvae identified. Collections of water in pools, ponds, ditches, streams, marshes, slit trenches, broken gourds, coconut shells, tin cans, tree holes, and the like, should be systematically sampled. Adult mosquitoes should be collected by means of suction tubes and other devices wherever resting places may occur, as in native habitations, barracks, tents, stables, pigpens, and privies, and in outdoor shelters such as tree holes, undercut banks of streams, sides of wells, and under bridges. The mosquitoes should be collected carefully and protected in pill boxes with cotton wadding so as to facilitate accurate microscopic identification. Individual collections in pill boxes should bear labels indicating date, locality, and whether collected in a stable, pigpen, house, tree hole, or other hiding place.

If the survey is a basic malaria survey, it becomes almost certainly a true piece of research, since the circumstances affecting malaria are extremely varied, with its triple-linked chain of man, parasite, and mosquito, plus all the varied factors influencing this chain. It involves a spleen census; a parasite index based on blood smears (thick and thin) to ascertain prevalence of the different species of *Plasmodia;* the sporozoite rate in the salivary glands of mosquitoes, the oocyte rate on the wall of the midgut of mosquitoes; meteorological factors; knowledge of farming practices, such as irrigation and rice culture; and much other information pertaining to both civil and military populations. Such a survey becomes the appropriate task of a malariologist in the true sense.

### Military malaria control

There are two basic military situations in which protection against malaria and other mosquito-transmitted diseases may be required: 1) fixed installations, including permanent and semi-permanent camps, shore stations, and fields, such as involve mass protection and attention to environmental measures; 2) field operations, requiring individual protective measures, environmental measures being secondary or entirely neglected under combat conditions.

*Environmental measures* consist of 1) selection of camp sites with reference to reasonable isolation from native villages, rice fields, swamps, and other mosquito hazards; 2) screening (see this Chapter); 3) naturalistic control methods (CHAPTER XVII); 4) drainage, filling, sluicing, etc. (CHAPTERS VIII, IX, X); and 5) use of larvicides (CHAPTERS XI, XII). It is particularly important that officers in charge of this program have a complete knowledge of species sanitation (see CHAPTER XVII).

*Individual measures* consist of the use of 1) bed nets (this Chapter); 2) repellents (this Chapter); 3) protective clothing; 4) suppressive treatment with quinine or atebrine. Under field conditions and particularly under combat situations individual methods are especially important.

*Malaria discipline* is defined by Russell[31] as "a state of orderly and effective conduct or action on the part of soldiers in respect to malaria control. It implies ability and readiness to practice malaria control, as outlined, particularly the individual measures."

MILITARY CONTROL OF OTHER MOSQUITO-BORNE DISEASES

Military control of other mosquito-borne diseases will require some modification of the procedures outlined for malaria-mosquito control. Modification of environmental measures is particularly necessary because of the different breeding habits of the species involved. Measures directed toward urban yellow fever control must fit the breeding habits of *Aedes aegypti* (see CHAPTER XVII). Jungle yellow fever requires still different measures because at least one of the known vectors, *Haemagogus capricornii*, breeds in trees high above the ground. In America and Africa the chief vector of dengue fever (a virus infection) is *Aedes aegypti*, hence the same environmental control measures as for yellow fever are applicable. But in the Pacific area the vector of dengue is *Aedes albopictus* and requires modified methods of control, *Aedes albopictus* breeding also in collections of water in jungle vegetation, and having a rural as well as an urban (domestic) distribution (see APPENDIX B).

Bancroft's filaria (*Wuchereria bancrofti*), the cause of a dangerous filariasis in many tropical and subtropical regions (particularly on many of the islands of the South Pacific), is transmitted by a large number of species of mosquitoes, their importance depending upon the particularly prevalent species in a given locality. Among the forty-four vectors (see APPENDIX B) *Culex quinquefasciatus* is especially important because it breeds abundantly over a wide area in all sorts of collections of fresh water. Procedures outlined in CHAPTER XV are applicable.

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# XV

## SPECIAL FEATURES OF MOSQUITO CONTROL IN URBAN AREAS

CITIES, ESPECIALLY the very large ones, often have a large production of mosquitoes which frequently cause intense localized nuisances. The places in which mosquitoes can and do breed within cities are very numerous, and an expert investigation of only a few hours in the heart of business and industrial districts of almost any city will demonstrate a relatively astonishing amount of mosquito production.

The species of mosquitoes which breed in cities are principally the domestic types such as *Culex pipiens*, *Culex quinquefasciatus*, and *Aedes aegypti;* however, a number of species of other genera, such as *Culiseta* (*Theobaldia*) and *Psorophora*, may be found where the conditions are suitable for their development. Man by his works presents numerous opportunities for mosquito breeding, of which the mosquitoes take prompt advantage. Mosquito control under urban conditions is a constant battle against human carelessness, ignorance, and even indifference.

### PUBLIC UTILITIES' STREET VAULTS

In practically all urban areas of any size, the various public utilities have numerous underground vaults in the streets, especially in the more congested business sections. These utilities are principally the telephone, power and light, gas, electric railway, and telegraph companies. The water company or department may also have a few underground vaults. Unless the sewer system is laid especially deep, these vaults are frequently not drained, or only partly drained. During the winter they will accumulate a quantity of water which may remain throughout the year. This water is not disturbed except when it is necessary for the utility company to work in the vaults. In most cases it will remain for many months.

In a large urban area the total mosquito output from such vaults may be very large. Table 9 shows the number of such vaults breeding mosquitoes in Berkeley, Oakland, Emeryville, Piedmont, and Alameda, contiguous cities in Alameda County, California, in June–July, 1933.

TABLE 9. Underground street vaults breeding mosquitoes (*Culex pipiens*) in Berkeley, Oakland,* Alameda, Emeryville, and Piedmont, California, June–July, 1933

| Name of utility | Total vaults | Breeding vaults *Number* | Breeding vaults *Per cent* |
|---|---|---|---|
| Pac. Tel. & Tel. Co. | 1,382 | 941 | *68.1* |
| Pac. Gas & Elec. Co.† | 1,404 | 731 | *52.1* |
| Southern Pacific Co. | 124 | 81 | *65.3* |
| Western Union Tel. Co. | 132 | 105 | *79.6* |
| Postal Tel. & Cable Co. | 44 | 33 | *75.0* |
| Total | 3,086 | 1,891 | *61.4* |

* Omitting East Oakland east of Fruitvale Avenue.
† Includes electric power, gas, and steam lines.

In addition to the vaults listed as breeding, there were several hundred additional vaults containing water but not breeding at the time of inspection. Many of these vaults would have been breeding if inspected later in the year. They are frequently the source of a severe local infestation, as many of them have a very large output of *Culex pipiens* during the summer and autumn months. In fact, the breeding often persists in deep vaults even during very severe winter weather. Our attention was called to this during one of the coldest spells (about 28° F.) ever experienced in Oakland, California, on December 11–12, 1932. On a complaint of a severe infestation of mosquitoes, a telephone vault in the street opposite the house from which the complaint was received was found to be swarming with adult *Culex pipiens*, and the water with larvae.

The ideal method of handling these vaults is to have them adequately drained, if the street sewer is set low enough; or if the grade of the sewer is not low enough, then to keep them pumped dry during the mosquito breeding season. In areas having a rainless summer, pumping would seem to be a practical method, though the utilities do not appear to favor it on account of the expense. One pumping after the conclusion of the spring rains would probably be sufficient for most vaults. But in regions having summer rains, pumping would require frequent repetition and would almost certainly be expensive.

Oiling or larviciding therefore is the only available procedure in most cases. Apparently routine oiling and re-oiling is necessary during the mosquito breeding season at intervals depending on local conditions. We have tried heavy oils and light oils, and find that the heavy oils tend to break into patches, resulting in a quick recurrence of breeding. Also, the utility companies as a rule object to the use of heavy oils which will leave a residue, as they claim that such oils or residues, if they get on a cable, make splicing difficult. We have tried a cresylic acid base larvicide with good results, but the laboratory of the Bell Telephone system has objected to its use in vaults on the ground that it might corrode the lead sheathing of cables. We doubt very much if there is any such danger in the dilutions used (1 to 10,000 approximately). A series of vaults in Oakland was treated with larvicide in June 1933, and up to October 1933 did not breed mosquitoes. As the water level was below the cables, we do not see how any corrosive effect could result, and none has been observed after six years.

We have not as yet tried either phenothiazine or dichloro-diphenyl-trichloroethane as a larvicide for these vaults, but we believe they are worth experimenting with for control of mosquito breeding therein.

We have found it possible to get cooperation from the various utilities in preventing mosquito breeding in these underground street vaults. Usually they have equipment which can be adapted to oiling the vaults. We have found it essential, however, to instruct their employees doing the work, and to check over their work from time to time. Otherwise, for lack of instruction and inspection, the work may be inadequately performed and considerable money spent by the utilities without satisfactory results.

One caution concerning the oiling of these street vaults should be observed. Many of them are located in the downtown sections of cities where the traffic is dense, usually in the traffic lanes. There is therefore considerable danger to the men doing the oiling, and extra precautions for their safety should be taken. We make a practice of driving the truck over the manhole and stopping just beyond it. Two or three red flags mounted on standards are then placed from ten to twenty feet back in the direction of traffic. Even with these precautions the men occasionally have to jump for safety, and several times each day the flags will be knocked down by careless drivers. As sewer

Figure 68. Pressure oil barrel on a light truck, used in oiling underground street vaults and street inlets

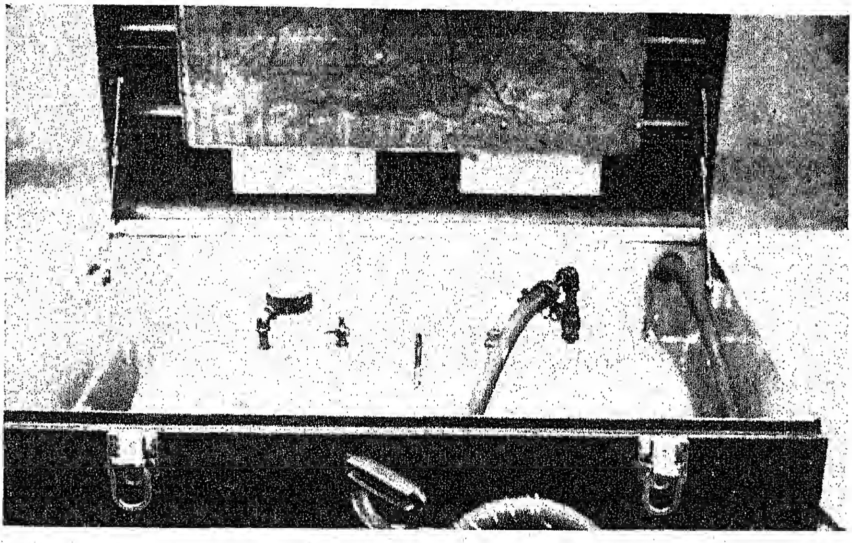

Figure 69. Interior of rear compartment of motorcycle oiling equipment, showing high-pressure oil tank and accessories

*Courtesy U. S. Public Health Service*

Figure 70. Cleaning a clogged roof gutter, to prevent the breeding of *Aedes aegypti* and other domestic mosquitoes

inlets and catch basins are usually at the curb line, the special precautions required in oiling street vaults are not so necessary for the protection of the workmen.

In oiling street vaults, catch basins, and inlets, we have used a simple and convenient equipment consisting of a strong steel barrel of fifty-five gallons capacity, provided with a three-eighths inch outlet pipe at one side of the periphery of the head, and a truck type Schrader air valve at the opposite side of the periphery. The air valve was tapped into the filling plug. The barrel was filled with forty-five gallons of oil, and then air (obtainable at any gasoline filling station) was put into the barrel under forty pounds per square inch pressure. About twenty-five feet of three-eighths inch heavy-pressure oil-resisting hose, with a spray nozzle, was attached to the outlet. With this equipment on a light truck, manned by a driver and one or two men to pull and replace manhole covers, the work was done fairly rapidly. We found a two-man crew necessary in oiling these street vaults, as in at least half the vaults the covers were so heavy that they required two men to handle them with any reasonable speed. In Washington, D.C., a somewhat similar arrangement has been used for catch basins and inlets. The oil tank under air pressure is carried in a sidecar motorcycle, the sidecar being on the left side.[1]

### Sewer inlets and catch basins

Inlets and catch basins on the sewer system may be a prolific source of mosquito breeding, if any water collects and remains therein. In the newer types of street inlets (see Figure 71) there is little or no opportunity for any water to collect and remain as a place for mosquito breeding, especially in inlets connecting to storm sewers. Most of the old type of catch basins, especially those connecting with a combined sewer (that is, a sewer that carries both domestic sewage and storm water run-off), are very apt to be mosquito breeders.

For example, in Oakland, Berkeley, Emeryville, Piedmont, Alameda, and San Leandro, contiguous cities in Alameda County, California, approximately 2200 oilings of inlets and catch basins were done on account of mosquito breeding between June 1 and September 30, 1933. The total number of inlets or catch basins breeding at one time is not known, as no survey was made to determine the number breeding, but in any city it is undoubtedly a significant factor

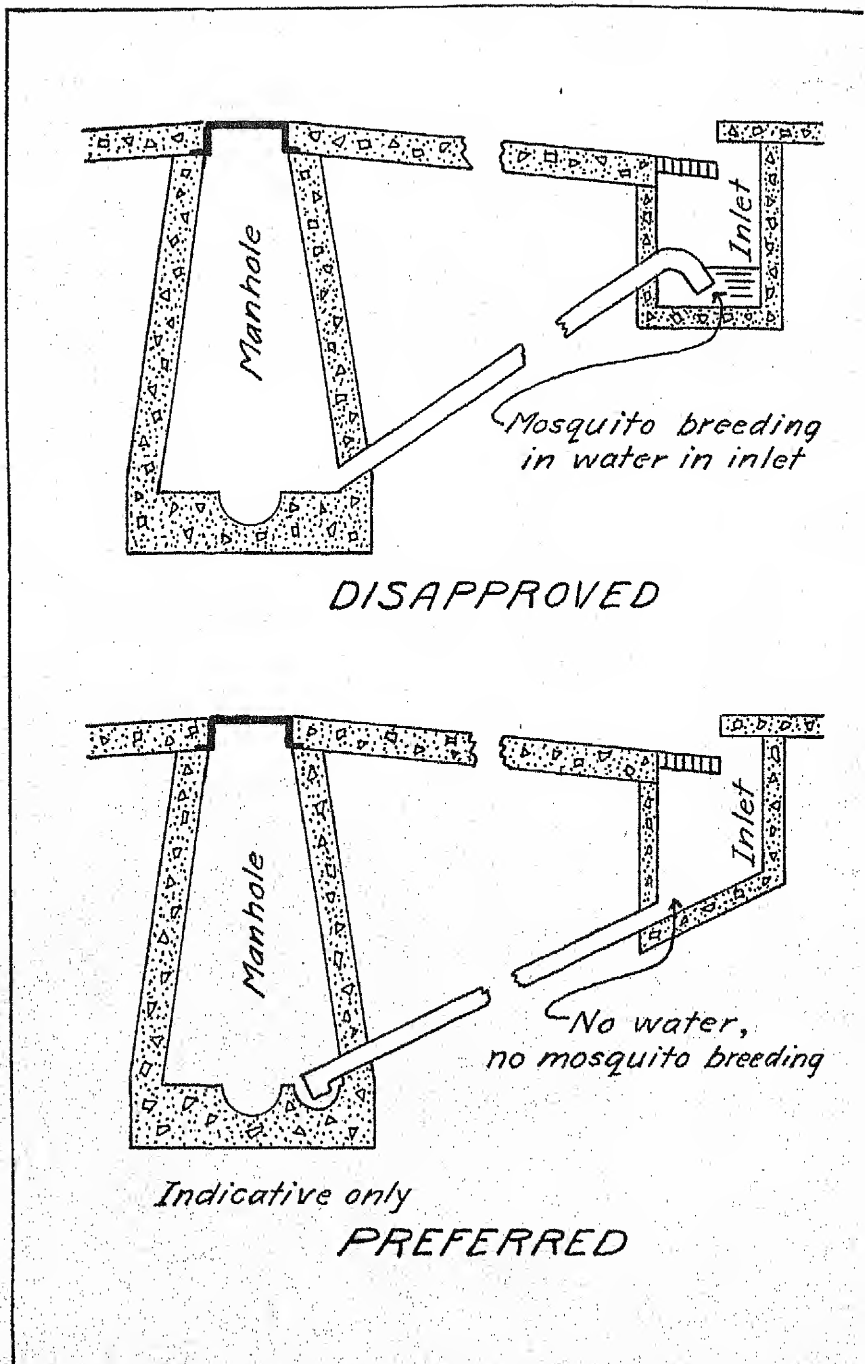


Figure 71. Disapproved and preferred types of street inlets

in the amount of mosquitoes present. In a large city it will probably be necessary to have a special crew with equipment to oil these structures routinely from May to October or November.

The Alameda County Mosquito Abatement District in 1935, after considerable study, developed a three-wheeled motorcycle equipment[2] which oils sewer inlets and catch basins far more rapidly and cheaply than had previously been possible. A Harley-Davidson type GD Servi-Car (three-wheeled, forty-five cubic inch engine) was purchased, and a special pressure oiling equipment mounted in the rear compartment. The equipment consists of a welded steel tank, eighteen inches in diameter and thirty-two inches in length, tested to 100 pounds per square inch pressure, but operating at fifty pounds maximum pressure. The tank has about thirty-two gallons capacity and is mounted in the compartment by means of two steel bands, welded to the tank, bolted to the front wall of the compartment, and screwed to the floor. Sufficient space is left to carry minor equipment, including a small fire extinguisher, shovel, first aid kit, and some miscellaneous small tools.

To accommodate the tank, the body was cut horizontally with a cutting torch, and an extra piece seven inches wide welded in to give the additional height required. After grinding down the welded seams, the body was then lacquered a brilliant scarlet so as to make it conspicuous, thus lessening the collision hazard while it is working on busy streets. The interior of the compartment and the tank were painted with an aluminum lacquer.

The tank is fitted along the top center line with an air pressure gauge, an air release petcock, an air inlet valve (Schrader truck type), a one and one-half inch brass filler plug, and a three-eighths inch brass outlet pipe with globe valve and hose connection. Fifteen feet of three-eighths inch, three-braid, oil-resistant hose are attached to the outlet pipe, and carried through a one inch diameter opening in the upper right hand corner of the front wall of the compartment, and then attached by a trigger-valve to a two foot length of three-eighths inch brass pipe to which is attached a Bordeaux spray nozzle. The brass pipe is attached by a hook (on a swivel) to the front end of the right rear fender. The nozzle is about four inches from the ground.

The operator drives the equipment directly over the catch basin; reaches for the trigger-valve directly back of his right hand and within easy reach; points the nozzle, by means of the brass pipe and the swivel clip, directly into the catch basin; and presses the trigger, releasing enough oil to spray the basin, including the sides above the water. Spraying the sides has been found to be quite effective in delaying re-infestation of the catch basin, as oil will gradually feed off the walls onto the water surface for a week or more after spraying. He then proceeds to the next catch basin. If the equipment cannot be placed directly over or alongside the catch basin, the brass pipe and nozzle can be removed from the hook, and enough hose pulled out to reach the inlet. This however is seldom necessary. A portable three gallon sprayer is attached to the back of the rear compartment for occasional oiling at a greater distance from the motorcycle than the available hose will permit. This has proved to be a real convenience and an economy, taking care of occasional oiling which would otherwise require a special trip by one of the district trucks.

Each morning the motorcycle's oil tank is filled with twenty-five gallons of oil and with air pressure to fifty pounds per square inch. This is obtained first from a compressor at the depot, and additional air needed during the day can be obtained at any convenient service station. One filling is usually more than sufficient for a day's work, as twenty-five gallons will oil from 200 to 250 catch basins.

This equipment with one man can oil from twenty-five to fifty per cent more catch basins per day, at a lower cost per mile for operation, than an automobile truck with two men. The total cost of the equipment was $607.60: the motorcycle cost $514.88; the tank with fittings and the enlargement of the body, $71.22; repainting the body, $15.00; the mounting for the three gallon sprayer, $6.50.

Although this equipment, which is a standard model slightly modified but unchanged mechanically, would be entirely satisfactory in fairly level territory, it was found to be inadequate in power and particularly in brake capacity for a region having a considerable amount of hill area. In Alameda County the terrain varies from sea-level to about 1700 feet in elevation. Therefore after four years' use this equipment was replaced in the spring of 1939 by a vehicle consisting of a sixty-one cubic inch overhead valve engine and motorcycle front end, and a rear chassis fabricated partly of automobile parts, with hydraulic brakes of ample capacity. The effective life of the rear chassis because of its sturdy construction is expected to be about twelve years; the effective life of the motorcycle engine and front end is expected to be about six years. The price of the new equipment, exclusive of the pressure tank and rear compartment transferred from the old vehicle, was $834.05. The operating cost of the new equipment is higher than the old equipment, but it is able to reach places in the hill areas heretofore inaccessible with the old equipment.

We estimate that the total cost of operating the present vehicle only, including insurance, repairs, depreciation, and interest on the investment, amounts to about 6 cents per mile. The gasoline consumption is eighteen miles per gallon.

Including all costs except supervision and office overhead, we estimate that the cost of oiling street inlets or catch basins with the present equipment is about 8 cents per catch basin oiled, or about 6 cents per catch basin inspected and oiled if needed. Excluding depreciation and interest, these costs are about 7 cents and 5 cents respectively.

As far as we know, the first use of a motorcycle side-car with a pressure tank for oiling was at Panama. In the United States, J. Lyell Clarke in Illinois was apparently the first to use such equipment, and he continues to use these "corner-cutters" effectively in the Des Plaines District. Washington, D.C.,[1] was also an early user of a side-car for this service.

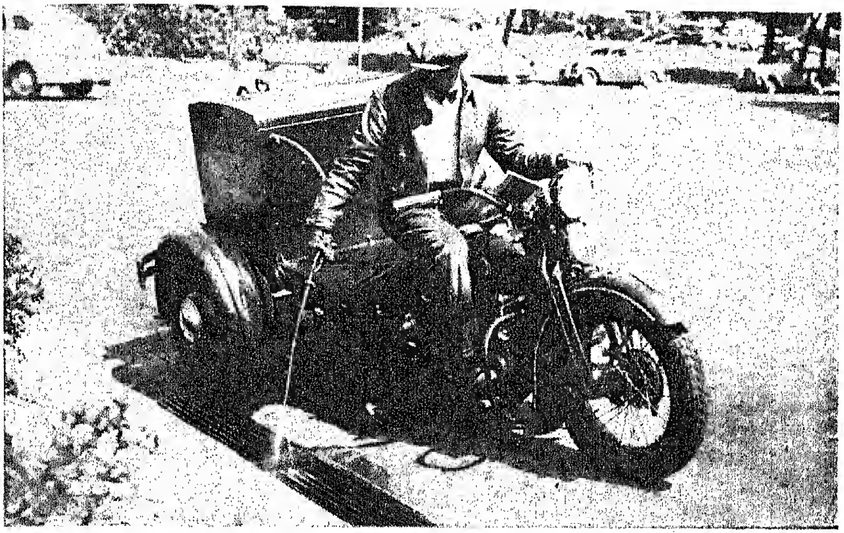

Figure 72. Three-wheeled motorcycle oiling equipment applying oil to a street inlet (catch basin)

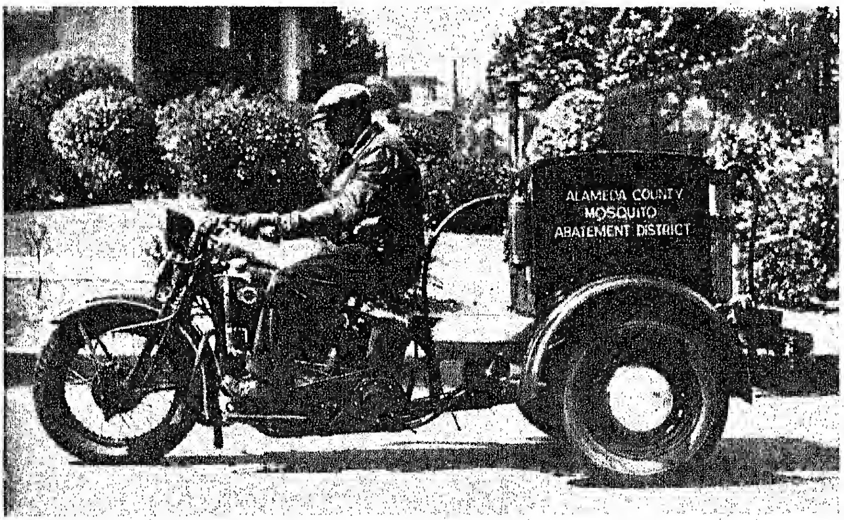


Figure 73. Three-wheeled motorcycle oiling equipment with automobile-type rear end

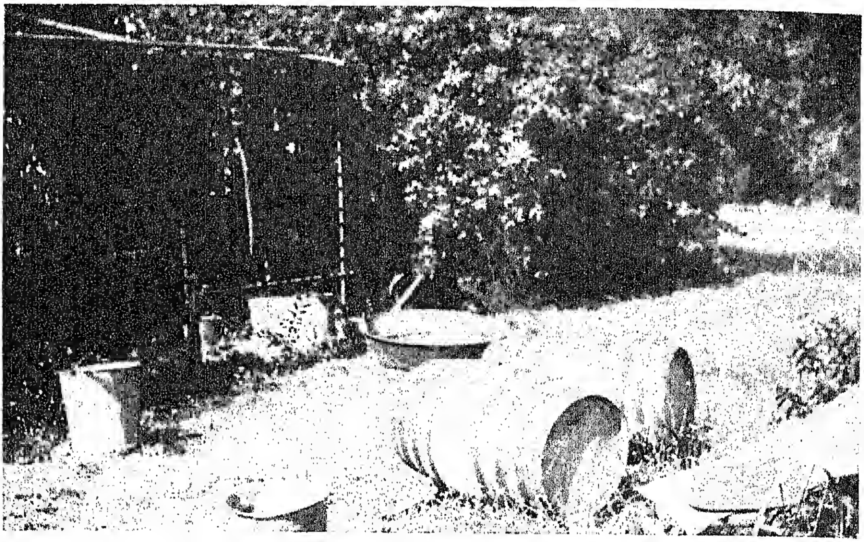

Figure 74. Tin cans, buckets, barrels, and other things that may hold water are excellent breeding places for domestic mosquitoes

Figure 75. Pickle vats out of service, in which mosquito breeding is controlled by fish

## Storm drains and street gutters

Mosquito breeding in storm drains is not a frequent occurrence, but occasionally it may be the cause of a very severe local infestation. A properly constructed storm sewer will not breed mosquitoes, as no water will remain stagnant in it; but a storm drain which has a carelessly constructed rough bottom, on which rubbish will catch and cause shallow pooling of water, may be a prolific breeder. This type of trouble is found only in flat bottom sewers; it is not encountered in circular or egg-shaped sewers unless there is an actual partial blockage or some structural damage to the sewer.

If a troublesome sewer is large enough for men to work in it, the best remedy is to give the bottom a smooth cement mortar finish to a uniform grade. If the sewer is too small for men to work in it, about the only thing that can be done is to flush it vigorously at frequent intervals. Dead ends on sanitary sewers having very flat grades may occasionally cause mosquito breeding, though this is rare. Frequent flushing is also the best method of handling such cases.

On flat grades on unpaved streets, especially in the smaller towns, water may collect in the street gutters and cause some mosquito breeding in the summer months. Although *Culex tarsalis* is the usual breeder, we have on a number of occasions found *Anopheles* larvae in street gutters in malarial regions. To prevent such breeding, the source of water should be cut off if possible, the gutter re-graded and the bottom made as uniform as possible, and any residual water oiled.

## Defective plumbing

One of the most difficult types of breeding place to locate and abate is that caused by defective plumbing. Under this classification we include: 1) broken or leaking plumbing, including house drains; 2) broken or leaking water pipes; 3) improperly connected or unconnected refrigerators; 4) building sumps and elevator pits; and 5) wet basements. Leaking pipes outside a house or building are easily located. Under a building they are sometimes found with difficulty, and may cause the accumulation of water which will breed mosquitoes.

Frequently leaking water will occur under houses or buildings with little or no head-room between the ground surface and the bottom of the floor joists. As a result the breeding water will be difficult to find, and when found it may be very difficult to determine what is the cause. Usually a plumber will have to be called to make the necessary repairs, at the expense of the property owners; and frequently it is advisable to enlist the aid of the city plumbing inspector and at times also of the health department.

A rather frequent source of mosquito breeding is the ice refrigerator drain. A small hole may be bored in the floor below the refrigerator, and the water from the melting ice dropped through it by means of a short rubber tube to the ground below, resulting in a pool of water. Such refrigerator drains should be connected to the main drain of the building by a trapped outlet.

### Building sumps and wet basements

In large buildings with deep basements, the basement drainage is frequently too low for gravity discharge into the city sewer system. In such cases the drainage is conducted to a sump, from which it is discharged into the street sewer by an automatic ejector. Occasionally the sump may be found to be breeding mosquitoes.

A peculiar instance which came to our attention in 1931 occurred at Fourteenth Street and Broadway in the heart of the business district of Oakland, California. A large department store became infested with mosquitoes (*Culex pipiens*). The office force on the second floor was attacked first, and in a short time the insects became so numerous that the customers were being attacked. When the matter was finally reported to the mosquito abatement district, the infestation was very severe. The source was found to be a sump and the channel leading to it, under the basement floor. The channel had several inches of water in it, caused by accumulations of muck on the bottom of the channel. The sump and channel were treated with larvicide to kill the larvae and pupae, after which the channel was cleaned and ordered flushed at monthly intervals. No further trouble has been experienced.

In handling these various types of breeding areas under buildings, the first abatement method is to eliminate the water in which the breeding occurs. The means must be adapted to the conditions found, and sometimes considerable ingenuity must be exercised. Pending the removal of the water, the application of a larvicide is advised. Oil should not be used under buildings, as it makes an unnecessary fire hazard.

We are frequently finding mosquito breeding under hastily constructed war industrial buildings and buildings at military posts.

Usually the trouble results from failure, through carelessness or haste, to backfill around foundation pillars. In wet weather water accumulates in these holes. Head room is usually slight and access difficult. Similar difficulties have been experienced with war housing projects.

### Other underground structures

Mosquito breeding in underground air-raid shelters may be quite a problem. When the London underground railways[3] were used as shelters, considerable annoyance from *Culex pipiens molestus* resulted. This species was found breeding profusely in the drainage sumps and in patches of water under the station platforms. In this case the breeding was controlled by oiling. Cresylic acid larvicide could also have been used effectively.

It is probable that an appreciable amount of mosquito breeding occurs in subways, but usually it goes unnoticed.

### Abandoned buildings

When a building is torn down or abandoned, it will frequently be found that the basement will fill with water during rains, and breed mosquitoes freely. In such cases the basement should be drained, filled in, or kept pumped dry, according to the conditions, and pending a permanent solution of the matter should be regularly oiled or treated with larvicide.

### Barrels, buckets, tin cans

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### Barrels, buckets, tin cans

In a well-regulated municipality having an adequate garbage and refuse collection system and routine sanitary inspection of premises, tin cans do not tend to accumulate on premises. But few towns have thorough and adequate collection and inspection services, and as a result tin cans accumulate, collect a small amount of water during rains, and so become breeding places. Such cans should be emptied, and the occupant of the property requested to have them removed. At times the cooperation of the city sanitary inspector is valuable.

One of the peculiar by-products of the depression, beginning in 1929, which was of considerable annoyance to mosquito abatement men, was the urban resident who apparently could not afford to pay for removal of the cans and rubbish from his premises, though he could maintain an automobile. Such people developed a pernicious habit of loading their tin cans into their cars and dumping them alongside the roadway in the less built-up and less frequented streets on the outskirts of cities. Numerous small mosquito-breeding places were thus created, as the cans filled with water during rains. No very effective remedy for this practice was devised; a special detail from the street cleaning department appeared to be the only possible action.

The amount of mosquito breeding in tin cans should be estimated on a quantitative basis, for in many situations the total production from cans is relatively small and its importance may be overestimated by the inexperienced. In hot, dry climates the water in metal containers exposed to direct sunlight may become too hot to permit survival of larvae.

During the present war the salvage of cans for tin recovery has in some areas reduced the number of cans available for mosquito breeding.

Other small containers of water, such as buckets or barrels, may be found on city premises for various reasons or for no reason at all. In cities having very hard water, rain water is frequently collected in barrels for special purposes. Metal buckets or barrels, when not in use, should be emptied and kept turned upside down. Wood barrels present a more difficult problem, as emptying them would cause the staves to dry out and make the barrels leaky and worthless. The application of larvicide to such containers is the most effective treatment, as one application is usually sufficient for a season.

However, if the barrel is used to collect water for a special purpose or is to contain foods or wine, neither larvicide nor oil can be used. Wine barrels in an Italian section are a frequent source of trouble, as when the wine is drawn they are filled with water until the next season. Such barrels must be tightly covered or screened in some manner so as to prevent entrance or egress by mosquitoes. Borax may be used as a larvicide on such containers under some conditions, and *Gambusia* may also be used with good effect in many cases. Inspectors should be cautioned not to dump such containers without first seeing the occupants of the premises, as any arbitrary action on these cases may cause considerable ill-feeling.

In addition to such containers, found usually on residential property, there may be tanks or vats on industrial property used in various manufacturing processes. These tanks or vats, when out of service, may be filled with water. In some industries and processes it may be possible to treat these tanks with oil without damage to the process. In others, for example wood vats in food preserving plants, neither oil nor larvicide may be used. Usually these tanks or vats are too large or too numerous to be covered effectively. If water is not expensive, the tanks can be dumped and refilled at intervals. We have used *Gambusia* successfully in preventing mosquito breeding in pickle vats temporarily out of service and held full of water to prevent stave shrinkage. A very light film of pyrethrum spray may sometimes be used. Here again we may find a situation calling for ingenuity.

### Roof gutters

In climates having summer rains, clogged or defective roof gutters may be the cause of some mosquito breeding. The obvious corrective measure is to have the gutters placed in good repair and proper working order. Sponges attached to long poles, by means of which gutter water can be absorbed, have been tried in some places, but this seems to be a waste of energy when the logical thing to do is to repair the gutter.

### Mosquito breeding inside houses

Mosquito breeding inside houses is encountered more often in tropical and semi-tropical regions than in temperate climates. Breeding may occur in water pitchers or slop jars not fully or frequently emptied, and in water containers in which ornamental plants are grown. *Aedes aegypti* breeds readily in containers *within* houses, to a much greater extent than either *Culex pipiens* or *Culex quinquefasciatus*.

As an illustration of breeding within and without houses, the biweekly reports of the *Aedes aegypti* control unit of the United States Public Health Service at New Orleans, Louisiana, for the period August 16 to October 15, 1943, show that on inspections 51,243 possible mosquito breeding places (barrels, tubs, buckets, tanks, cisterns, tin cans, bottles, tires, fish ponds, pools, boats, privies, cesspools, etc.) were discovered outside houses, of which 3691, or 7.2 per cent, were breeding *Aedes aegypti;* of 9244 possible breeding places (water plants, flower pots, unused toilets, ice-box pans, etc.) found inside houses, 540, or 5.8 per cent, were found breeding *Aedes aegypti.*

The number of possible breeding places inside houses was therefore 15.2 per cent of the total number of possible breeding places discovered; of the total places breeding *Aedes aegypti*, 12.8 per cent were inside houses.

On the basis of premises rather than of individual (container) breeding places, 34,941 premises were inspected during this period, with mosquito breeding being found on 3069 premises (8.8 per cent), of which 2741 were breeding *Aedes aegypti* (7.8 per cent of the total). Of those breeding *Aedes aegypti*, breeding occurred inside the houses in 412 premises which is 1.2 per cent of the total inspected, and 15.0 per cent of the premises breeding *Aedes aegypti*.

It is obvious from these figures that in *Aedes aegypti* areas inspections and corrections must be undertaken inside houses as well as outside; this will probably be a necessary measure in many tropical regions, whether *Aedes aegypti* is present or not, in order to effect adequate mosquito control for reasonable comfort.

In temperate climates mosquito breeding (usually *Culex pipiens molestus*) does not occur within houses with sufficient frequency to require routine inspections within houses. However, an occasional case will occur, and the possibility of such breeding should be kept in mind, especially when a sharply localized infestation persists after all outside breeding places have been corrected.

Two interesting cases which came to our attention are related as follows:

In the first, a municipal water department reported to the mosquito agency that one of its customers complained of mosquito larvae coming through the water pipes. On investigation it was found that the woman noticed the mosquito larvae in an aluminum pitcher which she had filled from the faucet immediately after several days' absence from home. Undoubtedly a little water had been left in the bottom of the pitcher during her absence, and a mosquito had laid her eggs thereon.

In the other case, a woman was experimenting with indoor plant raising, using a special solution of salts in which the roots of the plants were submerged, in place of earth. This solution was found to be infested with larvae and pupae of *Culex pipiens*.

## Ornamental garden ponds

The modern fad for ornamental garden pools has given the mosquito abatement men a problem that twenty years ago was practically non-existent. If these ponds were always properly cared for, and were always kept adequately stocked with fish which are efficient as larvae consumers, the ornamental garden pool would not be any problem. Sometimes a garden pool which has been well cared for in the past may be abandoned and neglected if the tenants remove and the premises remain vacant for any length of time.

Bearing in mind their limitations (see CHAPTER XIII) it is advisable to stock garden pools with *Gambusia affinis*, eight or ten fish for ten square feet of area being sufficient. The *Gambusia* will more or less regulate their own numbers according to the food supply available, the large fish eating their young if there is a shortage of food materials in the pool.

Goldfish may keep such ponds from breeding mosquitoes, provided the fish are sufficiently numerous and are not overfed, but they are rather uncertain as destroyers of mosquito larvae. Some of the varieties of ornamental tropical fish which are used in such ponds in warm climates are efficient as larvae destroyers, especially such fish as are surface feeders.[4]

Where intense mosquito breeding has been found in a garden pool (especially if there are pupae) the introduction of *Gambusia* will not prevent the emergence of quite a few mosquitoes from the pupae then in the pool. In that case it would be best to remove temporarily any aquatic plants, and apply a spray of either gasoline or pyrethrum extract. The latter is preferred, as it is very rapidly lethal to the larvae and pupae, and can be applied so lightly that it will all be evaporated in a few hours. Then the plants can be replaced and the fish introduced. In many cases, the pyrethrum extract can be used even without removing the plants or the fish from the water, provided it is used lightly and carefully. On account of the disfigurement and the unpleasant residue, the use of distillates and crude or semi-crude oils for mosquito destruction in garden pools should be avoided.

### Reservoirs and ponds

Distribution reservoirs or elevated tanks of a municipal water system are often accused, by persons living in their vicinity, of being a source of mosquitoes. However, we have never found any mosquito breeding in such reservoirs or tanks, and doubt if breeding does occur in them as long as they are in use, for the simple reason that the water is too much disturbed by the constant inflow and outflow.

We have occasionally found mosquito breeding in private swimming pools, or pools abandoned or temporarily out of service. Such pools are best treated with a pyrethrum spray, which will not leave any gummy or unsightly residue. If the pyrethrum is applied at night, the pool can be used the next day for swimming.

Park lakes and pools in cities may be stocked with *Gambusia* to prevent mosquito breeding. The bank edges should be cut down sharply so that there are no shallow margins into which the fish cannot penetrate.

### Sewage treatment works

Mosquito breeding is frequently troublesome around sewage treatment plants, especially those having units which are at times out of service. Breeding seldom occurs in tanks actively in service. A. M. Rawn of the Los Angeles County Sanitation Districts reports mosquito breeding in channels of sewage treatment plants where the sewage flow is at a very low velocity.

Where breeding occurs in such plants, it can be easily controlled by oiling as required. A distillate is entirely satisfactory for this purpose and if lightly applied as a spray will not have any adverse effect on any of the treatment processes.[5]

### Mosquito breeding in bombed areas

Aerial bombing causes craters which usually fill with water. These craters may be few and scattered, or many and concentrated, according to the intensity of bombing attacks. In urban areas and in rural districts where the land has good agricultural value, these craters probably will be filled in ultimately, but in the meantime they may be actual or potential mosquito breeders.

Little or no mosquito breeding will be expected in bomb craters during the first summer after their creation, for the reason that time will be required to establish in them the organic food materials required by mosquito larvae. In the second summer and thereafter, mosquito breeding may be expected, but the importance of the problem will depend on what species of mosquitoes find the craters to be suitable for breeding, and upon the location of the craters in relation to inhabited areas.

Bombing demolitions and fires result in exposed basements and cellars in which rain water or seepage water accumulates. In heavily bombed cities these are numerous. If the water is shallow, and particularly if it is well shaded by debris, breeding by *Culex pipiens molestus* will probably occur in temperate climates, and in tropical climates breeding by *Culex quinquefasciatus* and probably other species can be expected.

In bombed areas in England Shute[6] found that basements converted into water storage tanks for fire protection bred mosquitoes but slightly if the water was deep and the tanks were kept well filled, but breeding increased if the water was shallow. He also found little breeding if the water surface was well exposed to sunlight. In shaded tanks the species breeding was usually the non-biting *Culex pipiens pipiens*, which though not a problem because of biting, may cause appreciable loss of sleep in autumn when it enters houses prior to hibernation.

For control of mosquito breeding in craters in natural ground, consideration should be given to the use of copper sulphate to destroy the natural food organisms of mosquito larvae. Copper sulphate may be used at the rate of from one-half pound to one pound to 10,000 gallons (1333 cubic feet) of water, for this purpose. Cresylic acid larvicide at the rate of one gallon to 10,000 gallons of water can be used, and its effect may be expected to persist for several months. Either of the foregoing may also be used on basement or street tanks used for fire protection. Petroleum oils or pyrethrum larvicide may be used also, but will require more frequent application. We do not know that the newer larvicides, such as phenothiazine or dichloro-diphenyl-trichloroethane have been used for these types of breeding places, but they should be worth a trial. In mild climates the use of larvicidal fish should be effective if the water in the craters or cellars is permanent.

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# XVI

## SPECIAL FEATURES OF MOSQUITO CONTROL IN RURAL AREAS

THE CONDITIONS in rural areas which call for special adaptations of mosquito control measures are principally: 1) rural methods of water supply and sanitation; 2) liquid wastes from dairies and canneries; 3) duck clubs; and 4) impounded water. In addition, special problems arise from mosquito breeding along streams, in springs and ditches, in tree holes, and in cemetery urns.

### CESSPOOLS AND PRIVIES

As strictly rural areas do not have sewer systems, the disposal of fecal material and waste liquids is an individual problem for each residence. If the house is piped for running water, there is a problem in the disposal of liquid wastes; if not there is the problem of the outdoor privy.

Except in areas of high ground-water level, the privy pit seldom contains water and is of no importance as a mosquito breeder. The privy house, however, is commonly a harborage of adult mosquitoes. In wet areas the privy pit may contain enough water to be an excellent mosquito breeder. As these structures are maintained in mosquito-proof condition with difficulty (though they may be made and kept reasonably fly-proof) it is necessary under high ground-water conditions to use either oil or larvicide at frequent intervals to control mosquito breeding. Because of the disinfecting and deodorizing effect of cresylic acid larvicide, its use on wet privy pits is advised rather than oil. Chloride of lime (calcium hypochlorite) is frequently used as a deodorant in pit privies, but so far as we have observed it does not have any apparent effect on mosquito breeding in wet privy pits. Mosquitoes will breed in water having a free chlorine content of three or four parts per million.

In country houses having running water and modern plumbing, the liquid wastes, unless drained into mosquito-proof septic tanks or cesspools, often facilitate mosquito breeding. When these wastes are run from the house directly onto the ground surface, there is a health menace as well as a mosquito nuisance. In such cases the county health department should be called upon to help in having the wastes put underground where they will be less of a health hazard. Pending such improvement, the water should be oiled or treated with larvicide.

Where the liquid wastes are disposed of in leaching cesspools, mosquitoes can breed in enormous numbers unless the contents of the cesspool are thoroughly protected against entrance and egress by mosquitoes. The persistence with which *Culex pipiens molestus* in particular will find means to enter and breed in such cesspools is remarkable. The top of the cesspool should be covered with a layer of heavy tarred building paper and with at least a foot depth of earth, and any vent stack should be well screened with a fine bronze or copper screen. The soil pipe entering the cesspool should also be provided with an efficient trap and water seal. Mosquitoes have been observed to travel approximately 200 feet in horizontal runs of small diameter pipe, so that length of pipe is not a bar to their entrance to a cesspool.[1]

Where a cesspool is found to be breeding, the owner of the property should be urged to make the necessary changes to put it in mosquito-proof condition. Until this is done, the cesspool must be oiled or treated with larvicide at frequent intervals. In warm climates a ten-day interval is about the maximum time permissible between oilings if really effective control is to be maintained. In Eden and Washington Townships in Alameda County, California, 1487 cesspools were oiled from June 1 to September 30, 1933. This represents about one-half the number of oilings required for effective control, but was the most that could be done under the existing conditions.

It has been our experience that in cesspools which are sufficiently covered to exclude light completely or almost completely, *Culex pipiens molestus* or *Culex quinquefasciatus* will generally be the species of mosquito found breeding. But when the cesspool is poorly covered so that sunlight reaches to the water surface in the cesspool, *Culex tarsalis* will usually be the species found. As both species breed freely in foul water, the difference apparently lies in the reaction to light, *Culex tarsalis* requiring sunlight and *Culex pipiens molestus* avoiding it.

The occupants of premises having cesspools could save themselves considerable annoyance if they would put them into mosquito-proof condition, or failing that would oil them at frequent intervals. We find, though, that comparatively few people will do either. They prefer to grumble about the mosquitoes, rather than do a few simple things themselves to eliminate their own nuisance.

In recent years many so-called septic tanks have been sold for rural sewage disposal. These tanks consist essentially of one or two compartments, in which the sewage solids are settled out and more or less digested by anaerobic putrefaction. The partially clarified effluent from these tanks is disposed of usually by an underground system of drain tiles. Unless adequately covered and the contents protected by traps, with screens on vents, these tanks may also breed mosquitoes, though in general they seem to be less troublesome on this score than the cesspools. If breeding, they can be treated with oil. Larvicides should not be used on septic tanks, as they may interfere with the bacterial digestion of the settled solids.

### Liquid manure tanks

A condition somewhat similar to a cesspool is the liquid manure tank frequently found in connection with commercial greenhouses and plant nurseries. Into these tanks manures, fish meal, bone meal, dead animals and any nitrogenous material is thrown, and the tank filled with water. A strongly nitrogenous liquid of great fertilizing value, especially in "forcing" flowers and plants, is thus obtained. It is particularly nourishing to mosquito larvae, and almost unbelievable concentrations of larvae, especially *Culex tarsalis*, will often be found in such tanks. As the liquid is completely devoid of dissolved oxygen, the larvae and pupae spend practically all their time at the water surface; the concentration of organic matter is so great that they do not have to leave the surface to obtain food.

Nurserymen violently object to the use of oils or larvicides in these tanks, because of possible deleterious effect on plants when the fertilizer is used. We have found that a light application of pyrethrum extract (in kerosene) is very efficient in killing larvae and pupae, and is not objected to by the nurserymen. It must be repeated at sufficiently frequent intervals to prevent emergence of adult mosquitoes.

### Liquid wastes from dairy drains and canneries

Dairies use a considerable quantity of water, not only for cleaning utensils and for cooling but also for washing cows and cleaning the milking barn. These quantities are too large for underground disposal and contain considerable amounts of manure. As a rule these wastes are run into some sort of ponding device or sump in which the easily settleable portions of the manure are removed by a crude form of sedimentation; the overflow liquid is then removed in a drain ditch either to a near-by water course or to a disposal field on which it is spread out to leach away and evaporate. The liquid is rich in organic matter and is very fine breeding material for certain species of mosquitoes, especially *Culex tarsalis*. In uncontrolled dairy drainage the number of mosquito larvae will be almost unbelievably great.

In general, we have found no better way of handling dairy drainage than to keep the ditch as clear of vegetation as possible (usually a difficult job); to rotate the areas of field onto which the drainage is run, so that no water will stand on any plot long enough to mature a crop of mosquitoes; and to oil the sump, ditch, or disposal area whenever pupae appear in any part.

Canneries, which are frequently located in rural districts near the source of raw materials, also produce large quantities of liquid wastes. The same general methods just suggested for handling dairy wastes can be used also for cannery wastes.

It must be borne in mind that in either case no great expense for a wastes disposal project can be justified, since after the wastes have been treated by some method of sewage treatment, there still remains the water which is the mosquito breeding material. If, therefore, the wastes cannot be disposed of into a running stream without nuisance or danger of contaminating a water supply, there is no justification, from a mosquito abatement standpoint, of requiring the dairy or cannery to put in expensive treatment works. What may be required on the grounds of public nuisance due to offensive odors or stream pollution is something that must be handled by the health authorities. A failure to understand this distinction in functions may cause the mosquito abatement official some embarrassment.

### Watering troughs

Stock watering troughs may breed mosquitoes, but more frequently breeding occurs in wet areas adjacent to these troughs, caused by leakage or overflows. Leaks can be repaired and overflow prevented

Figure 76. Oiling a poorly constructed cesspool that breeds mosquitoes

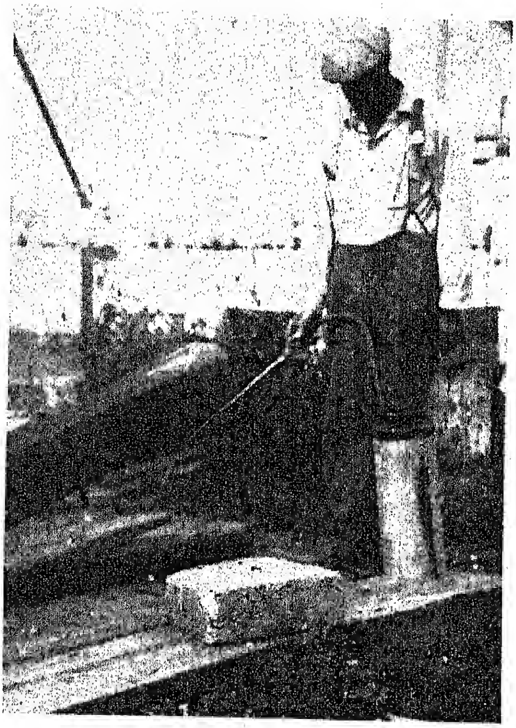


Figure 77. Defective plumbing in a labor shack makes an excellent mosquito breeding place

Figure 78. Oiling a sluggish stream in which mosquitoes breed

Figure 79. Oiling pools left by an intermittent stream

by greater carefulness or by putting on a ball float shut-off valve on the inlet pipe. It is also desirable that the area around and under the trough be covered by six inches or more depth of gravel, and the immediate vicinity of the trough slightly raised above the adjacent ground level.

*Gambusia* can be placed in watering troughs, and seem to thrive in them.

### Wells and cisterns

Breeding seldom if ever occurs in deep cased wells. Likewise, it seldom occurs in shallow uncased wells that are in constant use, probably for the reason that the removal of water causes more surface disturbance of the water than mosquitoes desire. Unused or infrequently used shallow wells are very apt to breed mosquitoes. Likewise, elevated tanks are rarely mosquito breeders, as the inflow and outflow of water disturbs the water surface too much; but if abandoned or seldom used, they may become breeders unless carefully screened and covered. Underground cisterns for storing rain water collected from roofs may breed mosquitoes prolifically.

Mosquito breeding in wells, cisterns, and elevated tanks may be abated by a light oiling with water-white kerosene or pyrethrum extract, applied as lightly as possible with a fine spray. This can be used without danger of an objectionable taste in the water, if the outlet is below the water surface. In mosquito infested regions such wells, cisterns, and tanks should be covered and screened to prevent access by mosquitoes to the water. *Gambusia* can often be used successfully in cisterns and wells.

### Rain and fire barrels

Where a cistern is not used, barrels may be provided for collecting rain water for washing purposes and occasionally for drinking water. Such barrels should be very carefully covered or screened to prevent breeding. If breeding is occurring, water-white kerosene should be used lightly to kill that crop of mosquitoes, and then an adequate cover or screen should be put on.

Fire barrels (barrels containing water for fire protection) are frequently found in rural areas, not only in the vicinity of residences and farm buildings but also along wooden railroad and highway structures. We have found that these fire barrels usually, in fact almost invariably, are mosquito breeders. One of the best methods of preventing breeding is to treat them with enough cresylic acid larvicide to give the water a distinct milky color. One such treatment will be effective for at least a year, and in all probability as long as the water is unchanged. Even if make-up water is added to take care of evaporation loss, the larvicide will still be strong enough to prevent breeding. It is of course a folly to treat fire barrels with an inflammable oil.

Another effective method is to use about four grams of a mixture of phenothiazine and a wetting agent (see page 241) to each fifty-five-gallon barrel. This will usually prevent mosquito breeding for at least three months. Borax (sodium borate) used at the rate of one to two pounds per fifty-five-gallon barrel will also usually prevent mosquito breeding for about six months, especially if about an ounce of copper sulphate is added to prevent the growth of algae.

### Streams, ditches, and springs

With some important exceptions (see chapter XVII) running streams and ditches will not breed mosquitoes. The presence of fish and the disturbance of the water surface usually make them unsuitable for breeding. However, sluggish streams and ditches, especially if they have much plant growth such as rushes, reeds, or tules which hamper the movement of fish, may breed mosquitoes. Shallow, grassy margins of streams and ditches may also furnish good conditions for mosquito breeding. Intermittent streams, which dry up in the summer months or flow only briefly after summer thunder showers, leave scattered, isolated pools along the stream bed which are often prolific mosquito breeders.

Streams on flat grades where mosquito breeding occurs should be channelized, that is, the banks should be straightened and cut down sharply at a steep angle, and the bottom cleared of vegetation and cut to an approximately uniform grade. In some cases it will be possible to give the stream a narrower and deeper channel which will confine the flow and increase its velocity. Worth[2] in Ceylon uses a method of silting the sides of streams, thus confining the main flow into a central channel. Lines of bamboo stakes form the silting basins. By these means mosquito breeding can be minimized or even prevented in flat sluggish sections of streams or ditches.

Pools left by temporary streams are more difficult to handle, especially on rocky bottoms. The cost of channelizing in such cases may be out of proportion to the benefits. In such cases occasional oiling of residual pools may be sufficient. The species of mosquito breeding in these residual pools should also be taken into consideration. Disease vectors should be effectively suppressed, especially *Anopheles superpictus* in areas where it is prevalent, but it may not be worth while to spend much time or effort in abating a primarily zoophilous species.

The method of intermittent flushing described in CHAPTER X may sometimes be used to prevent or minimize mosquito breeding in streams during periods of low flow.

Perennial streams and ditches may be stocked with *Gambusia affinis*, and frequently the fish will thrive. The *Gambusia* may be of little or no use, however, in intermittent streams, as drying up may result in loss of the fish.

Springs may give quite a lot of trouble: usually most of the mosquito breeding will occur in wet areas caused by overflow from the spring, but breeding may also occur within the spring. The overflow can usually be controlled by piping it to some point where it will run off rapidly on a steep slope. If this cannot be done, then the area around the spring should be filled with gravel sufficiently to stop any pooling of the overflow.

If breeding occurs in a spring, a difficult problem results. Fish will seldom live in springs, apparently for lack of natural food; larvicide cannot be used because of dilution, and not at all if the spring is used for human or animal water supply; oil is not desirable on a water supply spring, and will be removed rapidly by overflow from a flowing spring. The best solution is to enclose the spring in a concrete box with a tight cover, and conduct the outflow away in pipes. As a temporary measure, we have used a very light application of pyrethrum extract in kerosene. Even if removed quite promptly by the outflow, it is so toxic to the larvae and pupae that they are all killed by a single contact.

### TREE HOLES

In wooded areas, certain species of tree-hole breeding mosquitoes, such as *Aedes triseriatus* and *A. varipalpus* are especially annoying in their attack. Unless the persons in charge of the mosquito abatement work are reasonably well trained in the identification of mosquitoes, these species may not be recognized and as a result their breeding places may not be sought out and eliminated.

Tree surgery is the most satisfactory method of combating these pests. The breeding holes, often found in oak trees though also in maples, sycamores, eucalyptus, and many other trees, should be cleaned out, the debris and mud removed, and bark and rotting wood chipped out until sound wood is reached. The holes should then be filled with a mortar consisting of one part portland cement and three parts sand, mixed to a moderately moist consistency and well rammed into the hole. Enough should be used to raise the mortar a little above the edge of the hole, rounding it off, and dashing a little dry cement on the top, which should then be troweled to a smooth dense surface to shed the water.

When larvae are found in the tree holes, they are best killed with a cresylic acid larvicide. We have had good success in controlling the breeding of *Aedes varipalpus*, where we were unable to have the owners apply tree surgery, by the following method. All the tree holes in all the trees in the infested area are treated with undiluted cresylic acid larvicide, applied with a paint brush. The larvicide is painted onto the bark or onto the side wall of the tree hole immediately above the water line, and a little larvicide is allowed to run into the water in the hole and is stirred by the brush. If the hole is dry, the larvicide is painted onto the bark above the hole and well down into it. The latter is important, as the observations of W. C. Reeves (unpublished studies) on this mosquito in the act of ovipositing show that she lays her eggs on the side of the hole just above the water surface. The eggs are deposited singly on the side wall of the hole as she walks around the periphery just above the water surface.

This method not only kills any larvae and pupae in any of the holes which have water at the time of application, but also discourages or prevents the deposit of eggs. Also, enough larvicide will usually remain to mix with water from subsequent rains and so kill larvae which may hatch from previously deposited eggs. We suspect but are not certain that the larvicide may kill eggs with which it comes in direct contact, which is one of the reasons for painting the side walls of the tree holes.

In one group of sycamore trees where we applied this method during two successive years, the breeding of *Aedes varipalpus* was eliminated for at least four subsequent years without further treatment.

Because of its strong residue effect, it appears to be probable that dichloro-diphenyl-trichloroethane (DDT or Gesarol) may be an even more effective larvicide against tree-hole mosquito breeding, but we have not had an opportunity to try it for this purpose.

### Epiphytes

In many tropical regions there are found plants, designated as epiphytic bromeliads, which grow attached to trees, but subsisting on air and water. Some of these bromeliads have leaves which catch rain water, usually at the base where they attach to the trunk, and some species of mosquitoes breed freely therein. In the cocoa districts in Trinidad, for example, *Anopheles bellator*, the principal malaria vector, breeds in certain species of bromeliads, and in parts of South America (Venezuela) *Anopheles darlingi* is reported to breed in bromeliads.

Extirpation of the bromeliads may be the only effective method of preventing mosquito breeding in these air plants. This can best be accomplished by cutting them out of trees within the area to be protected. The liberal application of powdered copper sulphate will frequently kill the plants, but they may still continue to breed mosquitoes for some time.

As a temporary measure, spraying with a double strength pyrethrum-emulsion larvicide may be effective.

In Trinidad cutting out certain species of bromeliads within a radius of one-half mile around the cocoa plantations has been found to be effective for the control of malaria transmitted by *Anopheles bellator*.

### Cemetery urns

In cemeteries, containers are frequently provided for flowers on graves. These are filled with water which may stand for considerable lengths of time without changing. As a result these urns or cans may be mosquito breeding places, and in large cemeteries may produce a large total output.

This represents about the most difficult condition to handle, owing to the intermixture of sentiment and prejudice in the matter. In a large cemetery, treating these urns or containers with either oil or larvicide, or simply emptying them at sufficiently frequent intervals to prevent breeding, would involve a considerable labor cost. For example, in one cemetery having about 28,000 of these flower containers, the labor cost of emptying the containers twice a month was estimated to be about $700 per month for eight months a year, or a total of $5600 per annum (1941 wage scale).

Kelley[8] studied this problem in three cemeteries in Alameda County, California, and found eleven species of mosquitoes breeding, of which four were *Culex*, two *Culiseta* (*Theobaldia*), one *Aedes*, and four *Anopheles*. The most common species was *Culex pipiens*, probably *Culex pipiens pipiens*, as it did not require practically complete darkness on the breeding water, and it was not observed to bite, even late in the evening. The second most numerous species was *Culiseta incidens*. *Anopheles* mosquitoes ranged between 5 per cent and 10 per cent of the collections at different cemeteries, the most common species being *Anopheles punctipennis*.

Kelley found that in one active cemetery an average of slightly more than one container for every two graves was holding water, and one container to every four graves contained larvae (average twenty-five larvae per container). A type of metal flower container with a metal holder set in the soil, the container being inverted in the holder when not in use, was recommended as a means of minimizing mosquito breeding.

In New Orleans, Louisiana, during June, 1943, the United States Public Health Service, in making a survey of mosquito breeding in forty-one cemeteries, found 76,917 containers on 132,436 plots. Among the active cemeteries the average number of containers per plot was about two.

It is probable that on inspection any cemetery will be found to be breeding an appreciable number of mosquitoes, principally in flower containers. If the cemetery is located in a densely built-up urban area, this may result in a nuisance, and in some regions (especially *Aedes aegypti* areas) the production of disease vectors may be highly important.

Since the amount of labor required to inspect, empty and refill flower containers in cemeteries on a weekly basis during the mosquito breeding season apparently represents a prohibitive cost, some other method of control must be devised.

Paris green one part, mixed with plaster of Paris four parts, made with water into a soft pellet, and dropped into the flower containers, has been tried with fair success in some places. It has also been applied by hand and by squirting from a syringe. But apparently Paris green operates unevenly against non-anopheline larvae, and we have heard that in Texas it is ineffective against *Aedes aegypti.* Possibly the chemical properties of different waters may affect the toxicity of Paris green.

The most practicable control method at present available appears to be the application of phenothiazine to the water used for filling flower containers. For use at the New Orleans cemeteries the United States Public Health Service has developed a phenothiazine dispenser (Figure 80) to be attached to all filling hydrants. It consists of a one-and-one-half-inch pipe nipple about three inches long, which contains a cartridge (enclosed in a small muslin bag) of a mixture of phenothiazine and a wetting agent (see page 241). The cartridge is supported by a piece of copper wire screen held in place by a reducer screwed on to the bottom of the nipple. The top of the nipple is fitted with a similar threaded reducer which connects to the water pipe via an elbow, a vacuum breaker or check valve, and a globe valve. The handle of the regular faucet is removed, so that patrons must use phenothiazine-treated water for filling flower containers.

The phenothiazine cartridges are replaced in the dispenser from time to time as required, according to use. The use of a transparent plastic nipple would facilitate inspection for renewals.

For cemetery containers (as urns) which would not be filled with water from the dispensers, the use of phenothiazine-treated paper squares (see page 242), or phenothiazine applied from shakers (like pepper) would appear to be appropriate.

### Duck clubs

Duck clubs and mosquito abatement sometimes seem to be incompatible. Theoretically, there should be no conflict in their interests.

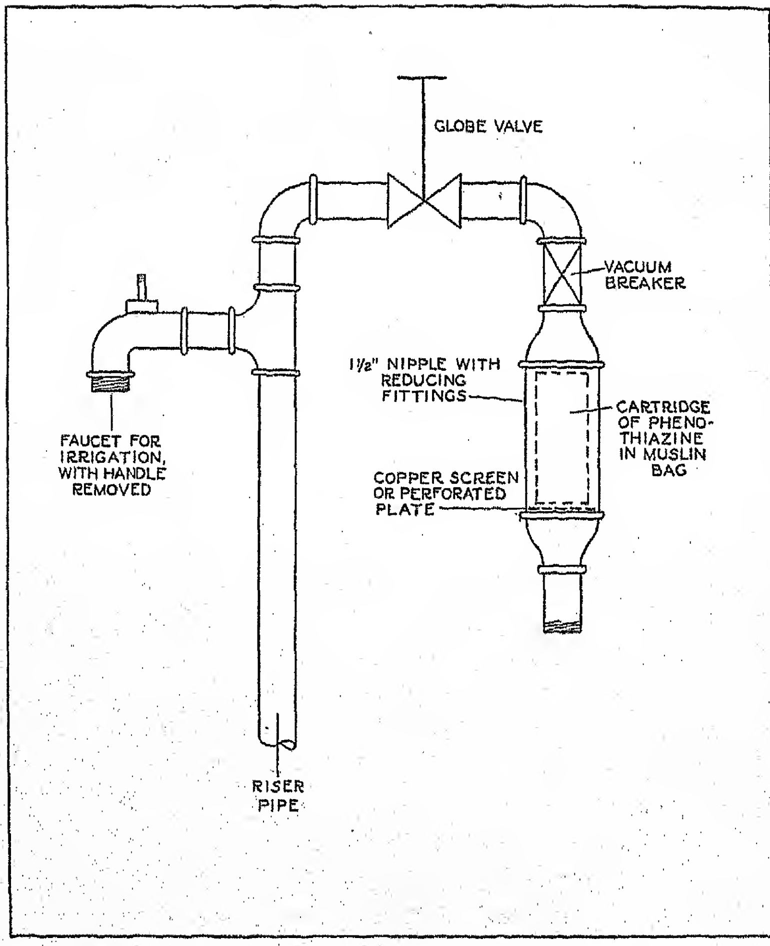



Figure 80. Phenothiazine dispenser for filling flower vases in cemeteries

Practically, because of the widely divergent views held by duck hunters, a great deal of difficulty will be found on some properties, but no trouble or very little trouble on others.

If the duck shooting season does not begin until November first or later when the weather is cold or cool enough either to stop mosquito breeding entirely or to slow it down so much that the output is small, no difficulty is encountered. But many clubs start flooding their duck ponds months before the season opens, either because inadequate pumping equipment makes prolonged pumping necessary or because they wish to have ponds ready in the early autumn to attract the forerunners of the main annual migration. In a few cases pumping begins as early as July.

A few clubs keep their ponds flooded throughout the year. These ponds are no problem if they have sharp, steep banks and no shallow spots into which fish cannot freely penetrate, and if the water is maintained at a constant elevation. Such continuously flooded ponds do not breed the most troublesome *Aedes* species, such as *Aedes dorsalis;* and the various species of *Culex* which might breed in permanent ponds usually can be controlled with *Gambusia* or other fish.

The ponds most difficult to handle are those which are drained off in January or February after the duck season is over, are allowed to remain dry during the summer, and are then gradually flooded in the late summer or early fall while the weather is warm and especially suited to mosquito breeding. Under such conditions breeding is sure to occur, and the mosquito abatement crew's troubles begin at once. As the water rises slowly, there is a constantly changing and very shallow margin. *Aedes* eggs from preceding years promptly hatch as the water reaches them. The margins where the larvae appear in greatest numbers are too shallow for effective fish control, and the duck club owners usually protest violently against the use of oil. The distillates kill vegetation, heavy oils leave an unpleasant residue, and crude oils may damage ducks by contact with their feathers. The mosquito men are emphatically not wanted anywhere in the vicinity because their presence may scare off ducks already there or deter others from coming in.

If you try to get the duck clubs to disk and level their ponds so that there are no shallow margins, and there is no vegetation with very shallow water standing on it (this is necessary if fish control is to be successful), you may find that the duck hunters of that club want a lot of shallow water and as much marsh grass as possible. At another club you will find hunters with an entirely different idea on the subject. No matter what is the logical and best method of handling a particular mosquito breeding condition on a duck club, a perverse fate may decree that that particular club is vehemently opposed to that particular procedure.

Much of the trouble encountered in handling duck club properties to prevent mosquito breeding is found in the almost infinitely varied ideas which are held by duck hunters as to the best methods of attracting ducks. Another source of trouble is the vehemence and bitter animosity with which some will resist anything tending to run contrary to their established habits and preconceived opinions.

Probably the majority of duck hunters are reasonable men and good citizens who would prefer not to have swarms of annoying mosquitoes on their duck preserves and who would not wish to have their properties the source of nuisance to others. But there are still too many duck hunters who seem to feel that as they have paid out considerable hard cash in making a place to which ducks will be tempted to come unsuspectingly to slaughter, they are entitled to conduct the property as they please, and that the public has no rights which they are bound to respect.

It is advisable to try to get along with the duck clubs peaceably and with the maximum possible amount of concession. Everything within reason should be done to show the duck clubs that the mosquito abatement men do not wish to interfere with their chances of a successful shooting season, and are trying conscientiously to respect the rights of the club as far as can be done without jeopardizing the rights of the general public. If within one or two seasons substantial progress is not made, then newspaper publicity should be resorted to for the purpose of building a public sentiment favorable to effective mosquito abatement procedures by the duck clubs. With this as a background the obdurate offenders should be prosecuted for maintaining a public nuisance, the most vociferous and offensive one being taken first. A few successful prosecutions of the worst offenders will probably be sufficient.

The following general propositions are set forth as the fundamentals of mosquito abatement on duck club properties. They must, of course, be modified in detail according to the special conditions existing on each property.

1. Continuous, all-year flooding of ponds is permissible and approved, provided the ponds are stocked with adequate larvicidal fish at all times and the water is maintained at a constant level.

2. Intermittent maintenance of ponds is permissible, provided: a) the water is effectively removed early in the spring before breeding can occur; and b) the water is not put into the ponds in the fall until the weather is sufficiently cool to prevent mosquito breeding; or c) controlled reflooding and redraining (see page 183) is practiced for a sufficient number of cycles to completely eliminate all hatchable *Aedes* eggs.

3. Ponds must have sound, tight banks and bottoms which will not cause adjacent wet areas due to leakage. This may require that the ponds be disked and dragged during the summer. A band of sheep herded on and around the pond area is an excellent method of mulching and tamping the pond bottom and banks so as to make them tight and conserve water. The use of bentonite (a special type of clay) will usually stop leakage in even a very porous soil. The best method is to remove about six inches depth of soil from the bottom and sides of the pond, spread a layer of bentonite two inches thick, replace the removed soil carefully, and tamp or roll it. When flooded, the water causes the bentonite to swell and form a nearly watertight membrane.

If, however, nothing is done to prevent pond leakage, then adequate drain ditches must be installed around the pond to intercept the seepage and conduct it away to a main drain or to a natural watercourse.

4. Ponds must have sufficient depth throughout to avoid shallow areas into which fish cannot penetrate effectively. This is essential whether the ponds are continuously or intermittently flooded. Careful leveling of the bottom of an artificial pond is very desirable.

5. Ponds must not be overgrown with vegetation, especially near and along the margins. Such vegetation prevents fish from effectively destroying mosquito larvae. Vegetation should be kept down either by mowing or preferably by disking, during the period when ponds are dry.

6. If the pond water is pumped, the water supply and the pumping equipment should be adequate to fill the ponds with reasonable speed.

7. If grass or vegetated areas are desired adjacent or contiguous to the ponds, these should be leveled off at about one foot above the water level of the ponds, so that there will be no low wet spots in the grass that may become mosquito breeding places.

8. Intermittent flooding or flooding early in the autumn may be permitted if there are effective drains leading to sufficient outlet gates of adequate ca-

pacity to drain the entire flooded area within two or three days, so that extensive mosquito breeding can be stopped promptly by draining the area. The gates should discharge into a bay, slough, stream, or body of water where mosquito larvae will perish or be consumed by fish.

9. The inspectors of the mosquito abatement district must be permitted to inspect the area frequently to determine whether or not breeding is occurring.

10. If larvae do appear, in spite of all measures that can be taken to prevent breeding, then oiling or larviciding must be permitted to prevent emergence of mosquitoes. If only a comparatively small amount of oiling is to be done, water-white kerosene may be used because it leaves no residue, it does not damage vegetation appreciably, and it does not seem to deter the ducks. If extensive areas are to be treated, an emulsion of pyrethrum concentrate with kerosene and an emulsifier will probably be the most acceptable effective control measure.

11. For the reason that duck clubs impose additional costs upon mosquito abatement or public health agencies, it seems to be logical and reasonable that at least a large part of such added costs of mosquito control should be borne by the duck clubs.

### Impounded water

The impounding or storage of water in reservoirs of any considerable size occurs usually under rural conditions. Storage reservoirs for water within cities are small or of moderate size, are almost invariably constructed with concrete or masonry bottoms and walls, are frequently covered or roofed over, and sometimes are completely screened. The constant inflow of water, the clean sides and bottoms, and the disturbance of the water surface make the urban storage reservoir unsuitable for mosquito breeding, and mosquito larvae are seldom or never found therein. However, the impounding of water in large storage reservoirs, usually behind dams in streams, for water supply, irrigation, hydroelectric power, or navigation, presents an entirely different situation.

In the area from the Rocky Mountains to the Pacific Coast, where such reservoirs are formed usually in river canyons with steep-sided, rocky walls and floor, the amount of mosquito breeding generally is negligible or practically absent. When it occurs, it is found at marginal areas, especially near the upper end, where the terrain flattens and leaves a shallow flooded area with more or less vegetation. As a rule, also, such reservoirs in the western states are located at considerable distances from any communities, so that even if mosquito breeding does occur, it does not constitute a nuisance or a health problem.

In other parts of the world and wherever rivers with comparatively flat grades flow through a terrain of low relief, such reservoirs, whether for power, irrigation, or navigation, especially if not stripped, may become excellent breeding places for both anopheline and culicine mosquitoes.

Carter, LePrince, and Griffitts[4] called attention to mosquito breeding in such impounded water as far back as 1915, and showed that it was important to eliminate the organic floatage which provides protective shelter for *Anopheles quadrimaculatus* larvae. As the reservoirs they studied had not been stripped before flooding, they recommended carrying the water level as high as possible during the winter months and as low as possible during the summer, with variations of levels on flood flows, for the double purpose of killing vegetation in the reservoir and for stranding floatage along the banks.

Smillie[5] studied the effect of a newly constructed impounding reservoir for power development on the malaria incidence of an adjacent community in Alabama. The reservoir site was not stripped at first, and a considerable amount of *Anopheles* breeding occurred with a sharp outbreak of malaria as a result. Later this reservoir was stripped of vegetation in accordance with the regulations of the state board of health, resulting in a marked improvement in *Anopheles* control and in an abrupt lowering of malaria incidence. Smillie also called attention to the reduction of mosquito production due to intentionally caused variations in the water level of the reservoir. He found a flight range of about one mile for *Anopheles quadrimaculatus* at this reservoir.

The first state regulations governing the control of mosquito breeding in impounded water were promulgated in Alabama and Virginia in 1922.[6] Since then several southern states have passed regulations governing mosquito control in reservoirs. In general the regulations endeavor to provide conditions in reservoirs which will either eliminate or minimize mosquito breeding, or establish conditions favorable to the effective and economical control of mosquito breeding.

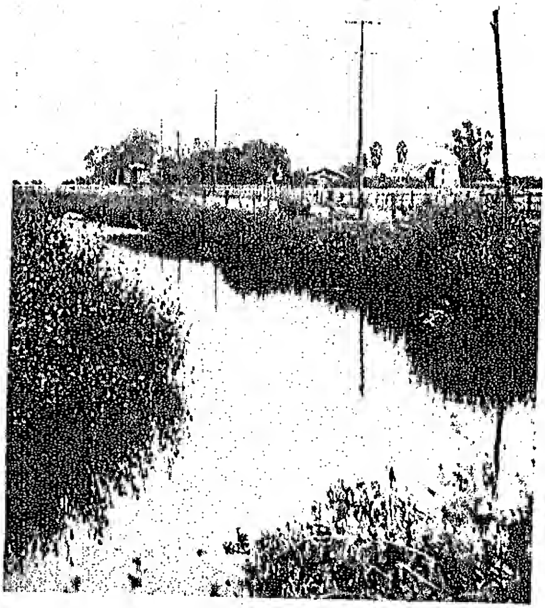
The engineering design of dams in malarial areas should incorporate devices for regulation of the water level in the reservoir, particularly for the purpose of causing fluctuations in water level at appropriate times according to season and stream flow. It may be difficult to reconcile the requirements of flood control, irrigation, domestic water supply, hydroelectric power, navigation, and mosquito control, but fortunately all these factors are usually not present in one reservoir. In general, mosquito control requires that the water level be carried at a high elevation in winter and spring in order to kill shoreline vegetation, and then lowered during the summer and fall. This may conflict with flood control requirements of a low water level in winter and spring in order to provide storage space to hold the winter and spring flood flows. Also, mosquito control requires that during the *Anopheles* breeding season there be periodic fluctuations in water level in the reservoir at weekly or ten-day intervals, partly to minimize aquatic or semi-aquatic growths at the shore line, and partly to strand the larvae of mosquitoes near shore or else to carry them into deeper water where they are more exposed to predators or to surface disturbance which prevents successful emergence from the aquatic stage. Such fluctuations may not fit in with the requirements of power, irrigation, or municipal water supply, on account of the variation in operating head or the wastage of water.

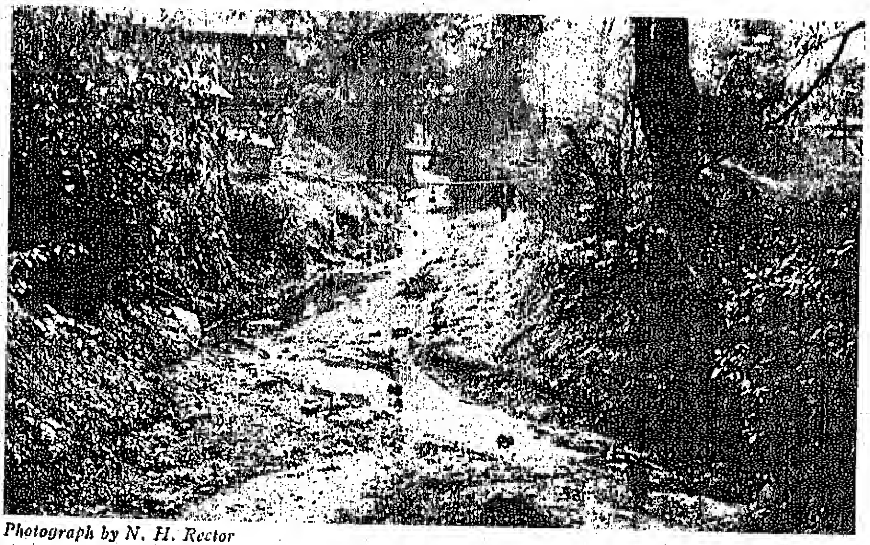
Water level fluctuation may not be depended on by itself as a mosquito control method, and usually supplementary control methods must be used.

In malarial areas in particular, stripping or clearing of the inundated area is essential. For domestic water supply the clearing is usually complete, to minimize objectionable tastes and odors. In reservoirs for power, irrigation, or navigation, complete stripping may not be considered essential for such purposes, but for mosquito control purposes it should be very thorough to reduce organic floatage to the smallest possible amount. The stripping should include a peripheral strip of ten feet in elevation above the flood water level. All trees should be logged off and removed if they are merchantable, and all brush, limbs, down timber, and organic trash piled and completely burned.

During the construction of the dam, water should not be impounded during the mosquito breeding season. Any accumulation of water should be scheduled for the winter months only. After the reservoir is placed in operation, floatage should be passed over the dam spillway

Figure 81. Lower end of a dairy drain, a large producer of *Culex tarsalis*





*Photograph by N. H. Rector*

Figure 82. Typical drainage way that breeds *Anopheles quadrimaculatus*

Figure 83. Mosquito breeding pools in rear of a small cannery, caused by inadequate drainage

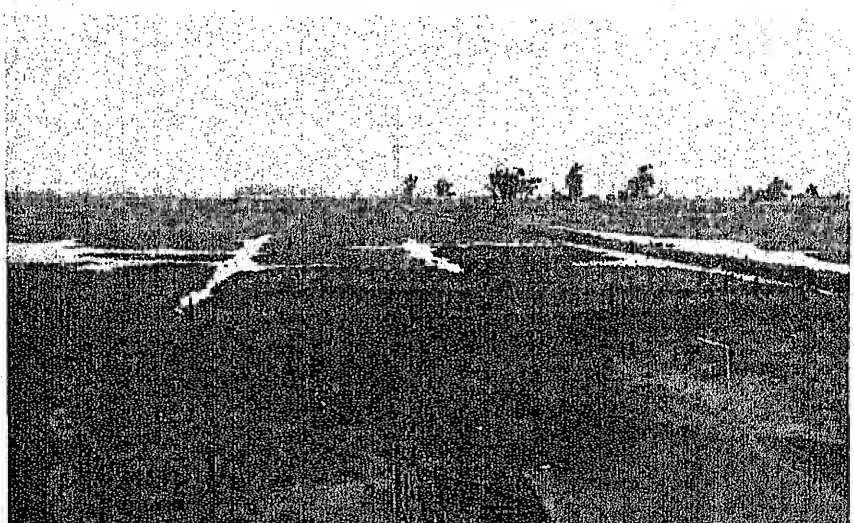


Figure 84. Duck club area being flooded in August. Shallow water under dense grass makes mosquito abatement difficult

as far as possible, or stranded on shore and piled and burned. Fluctuations in water level will assist in these procedures. It may take several seasons to eliminate the greatest part of such floatage.

The Tennessee Valley Authority has on some reservoirs dyked off shallow marginal areas, from which the water is pumped to dry them out and eliminate marginal breeding.

These measures will minimize littoral mosquito breeding but probably will not completely eliminate it, and supplementary larvicidal procedures will be required. Oil and Paris green are most used for this purpose, oil having probably a wider applicability, as it may be inadvisable, because of its effect on the public prejudices, to use Paris green on reservoirs used for municipal water supply. Either oil or Paris green can be applied by aeroplanes, power launches, or boats. Power launches for use on large reservoirs should have a minimum length of twenty-four feet, and should have an inboard motor, electrically started. They should be equipped with either power dusting or power spraying devices, for rapid and economical application of the Paris green or oil.

Large reservoirs in a malarial area should be inspected and mosquito control work supervised by a trained and experienced man assigned to the work. He should keep complete records of operations, including larval dippings and mosquito catches.

If a new impounding reservoir is to be built within any reasonable distance of human habitations, a careful survey of mosquito and malaria prevalence should first be made by competent investigators, and the data preserved under affidavit and sealed, for future use in case lawsuits for damages should be filed after the reservoir is completed.[7] Unless this information is collected and preserved, the defense against such suits may be difficult.

To minimize or obviate such suits, what are designated as "night easements" have been purchased on lands adjacent to reservoirs. By such easements the property owner abandons the right to occupy the property between sunset and sunrise.

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# XVII

## SPECIES SANITATION AND NATURALISTIC CONTROL

As IN many fields of man's endeavor to improve conditions of living, the control of mosquitoes to date has made great strides through applications of engineering. Biological knowledge, in this case knowledge of mosquito species, habits, and ecology, has made fundamental contributions but, owing to the more elusive intricacies of the biological organism, has as usual lagged behind the knowledge and application of physical science. It is entirely probable, however, that progress toward effective control of these pests, particularly the disease vectors, will from now on depend increasingly on the extension and application of biological knowledge. For this reason we have continually stressed throughout this book the importance in abatement procedures of the identification of the offending species and the application of biological measures to the fullest possible extent. The subject is far too large for comprehensive discussion in a handbook of this character, but it is hoped that the brief presentation of the subject in this final chapter will leave the reader with a biological point of view on the problem and stimulate a desire to read and to work more intensively along these lines.

Many years ago, when it became known that mosquitoes breed in standing water, the obvious corollary was: "No standing water, no mosquitoes." Following the important discovery by Ronald Ross in 1897 that malaria is carried by mosquitoes, this corollary was expanded into the slogan, "No standing water, no mosquitoes; no mosquitoes, *no malaria.*" It all *seemed very simple;* but we had *much* to learn. As Hackett[1] has pointed out, the early investigators found localities in Europe with great numbers of anopheline mosquitoes which had no malaria; and also localities with a relatively small number of anophelines which had a high incidence of malaria. Likewise, there was no malaria in some swampy regions; and there was a great deal of malaria in some regions without swamps.

### *SPECIES SANITATION*

Ross in 1899 had foreshadowed this problem when in his work in

India he propounded two questions of fundamental importance: 1) what species of mosquitoes do and do not carry malaria? and 2) what are the habits of the dangerous varieties? He had recognized three types of mosquitoes which he called brindled, grey, and dappled-winged, later distinguished as *Culex*, *Aedes*, and *Anopheles* respectively. He found that his dappled-winged mosquitoes (*Anopheles*) were the transmitters of malaria, and he believed that by feeding such species on persons known to have malaria gametocytes in their blood, the dangerous types of mosquitoes could be determined. But as all species of *Anopheles* presumably can be infected under laboratory conditions, the control of malaria by means of *Anopheles* control appeared impracticable if not impossible. And this view was reinforced by the failure of an inadequately conducted mosquito control experiment at Mian Mar in 1901, which set back progress in malaria and mosquito control in India for many years.[2]

In Malaya, however, malaria research was begun in 1900 and has continued to this day. Sir Malcolm Watson,[3] after an initial success in controlling malaria at Klang and Port Swettenham in 1901, began the fruitful investigations which showed that the problem of malaria control was entirely different in the hill areas than in the swamp areas. In the latter, open drainage was effective in controlling *Anopheles umbrosus*, which was proved to be the carrier in the lowlands of Malaya; but in the hill areas such drainage had no effect except to increase the malaria. The reason for this was that the hill area malaria was transmitted principally by *Anopheles maculatus*, a sun-loving stream breeder, and that the other dozen or so species of *Anopheles* were not important as vectors of the disease.

And so developed the idea, since abundantly proved in many instances, that in any malarial area only one or at most a very few of the local *Anopheles* species is the effective vector of malaria *in that area*; that malaria can be controlled in that area at reasonable cost by attacking the specific vector *Anopheles* species; and that usually some simple and perhaps relatively small change in environmental conditions will make it difficult or impossible for the specific vector to breed in appreciable numbers. This was the beginning of "species sanitation," a term coined by Swellengrebel.[4] It is an apt expression implying that the control measures must fit the particular offending species.

Failure to recognize the difference in *Anopheles* breeding habits and other variations in their ecology was to prove costly in many cases. One of the most interesting situations was in the Philippine Islands (Luzon) at the time of the American occupation (1898 *et seq.*). The Army medical officers had been led to look upon marsh areas as malarious and to regard the lowlands, in the vicinity of Manila, for example, as extremely dangerous to the troops. Actually there was a low incidence of malaria in and about Manila, where the dominant anopheline, *A. ludlowi*, is a poor transmitter under natural conditions; but the rigidly held idea that "marshes equal malaria" led to the stationing of troops as much as possible in the hill areas near running water. Malaria promptly became a scourge among troops and civilians so situated, while the disease remained relatively slight among troops and civilians quartered by necessity in the supposedly malarious lowlands. A report by Crosby and Whitmore in 1904, buried in the medical records of Fort Stotsenburg and long neglected,[5] showed that the stream-breeding *Anopheles minimus flavirostris* of the hill areas was an important vector, in fact *the* vector of malaria in Luzon. But it took twenty-one years (to 1925) for this information to be acted upon, even though Walker and Barber[6] in 1914 had again showed the stream-breeding *A. minimus flavirostris* to be the dangerous vector.

Furthermore, it was discovered that certain types of breeding areas may be dangerous in some regions yet innocuous in other regions. Watson found that the Krian rice fields in Malaya were healthy but that the Buket Gantang rice fields were malarious, owing to differences in the *Anopheles* fauna. Rice field areas in China usually are malarious, due not to *Anopheles* breeding in the rice paddies, but to *Anopheles minimus* breeding in the streams and ditches bringing water to the rice paddies. In some parts of Spain (for example, Valencia) rice culture is non-malarious, though the fields produce *A. melanoon* abundantly. In Portugal and in other parts of Spain rice fields produce the vector, *Anopheles labranchiae atroparvus*, and are malarious.

### Experience in California

When we[7] first began malaria control in California in 1910, it was obvious from the observed habits of the three species of *Anopheles* mosquitoes in California that one species, *Anopheles pseudopunctipennis*, could have relatively little influence upon malaria transmission, as it was rarely taken within houses. It was a field mosquito rather than a domestic or house mosquito. It might be effective as a vector where large numbers of persons slept out of doors or in poorly constructed shacks, but not among populations reasonably well housed. *Anopheles punctipennis* was more frequently taken in houses, though we characterized it as typically a "porch biter," but it was relatively not numerous in comparison with other anophelines in malarious districts,[8] and its seasonal distribution differed from the seasonal distribution of malaria. This insect was relatively more numerous in the spring and early summer, and relatively less numerous in the late summer and autumn when malaria was at its peak.

But *Anopheles maculipennis* did fit the seasonal distribution of the disease, did enter houses freely and attack man, had more or less domestic breeding habits, and dissections indicated that specimens in malarious areas were infected. But here we were faced with a paradoxical situation. *A. maculipennis* was also found abundantly in the coastal counties where no malaria occurred, as well as in the interior valleys where malaria was endemic. We tried to answer this paradox with the fact that the average sustained summer temperature in the coastal counties was too low for the maturation of gametocytes in the mosquito; but in the vicinity of Menlo Park where *A. maculipennis* was abundant this temperature explanation was of very doubtful validity if not positively wrong. It was not until nearly thirty years later that T. H. G. Aitken[9] showed that we had two subspecies of *A. maculipennis*, an interior variety *A. maculipennis freeborni* Aitken which is an efficient vector of malaria, and a coastal variety *A. maculipennis occidentalis* (Dyar and Knab) which is not normally a malaria vector.

Further, *A. maculipennis freeborni* did not conform strictly to the formula of standing or stagnant water. It would not breed appreciably in stagnant or foul water and but seldom in deep or impounded water. Its obvious preference was for relatively cool, sunlit, shallow seepage water in the presence of vegetation. This condition was presented wherever irrigation was practiced, owing to leakage from new unlined irrigation canals or from poorly maintained canals and ditches, and from excessive applications of irrigation water in the early days of irrigation in northern California when water was cheap and abundant in relation to the acreage under irrigation. In later years higher cost of water and its lessened relative abundance brought about conservation of irrigation water in distribution and use, which undoubtedly resulted in a diminution of the numbers of *A. maculipennis freeborni*, irrespective of any mosquito abatement measures.

Our prompt recognition of irrigation seepage as an important factor, emphasis on *Anopheles maculipennis* as the principal vector, and direct selective attack upon this vector produced almost startling results in the reduction or even in some cases complete extirpation of malaria in limited areas (for example, Penryn) where malaria was endemic, at a small cost for the control measures. We were even able to get excellent malaria control in purely rural areas as well as in urban areas at a reasonable cost, contrary to Ross's original expectation and prophecy.

The observed characteristics of this mosquito also explain why malaria was such a scourge of the gold camps under placer mining conditions in California in the 1850's (it was called miner's fever), though it does not directly explain the terrific epidemics of malaria in the United States Army posts at Camp Far West, thirty-five miles north of Sacramento, and at Camp Reading (now Redding) which were so severe that these posts were abandoned, the first in 1852 and the second in 1856.[10] However, the outbreak of malaria near Lodi in 1934 and 1936[11] showed that when large numbers of both infected and non-infected persons camp out in the open under relatively primitive conditions (which occurred in the great depression migration of 1934 to 1937) the transmission of malaria by the available vector anophelines is bound to occur. Probably the conditions in 1852–56 and 1934–36 were similar.

### Experience in the central and southern states

In the central and southern sections of the United States it was recognized relatively early that the principal vector of malaria was *Anopheles quadrimaculatus*, a typical pond breeder, and that other anophelines, such as *A. crucians*, were relatively of less importance. *A. quadrimaculatus* has continued to be a distinct entity without apparent subspecies. While there has been considerable confusion in separating *A. maculipennis freeborni* from *A. quadrimaculatus*, the two species are entirely distinct ecologically, and control measures which would have been effective against one would have failed against the other.

The fact that *A. quadrimaculatus* is typically a pond or impounded water breeder has made necessary extensive control measures on hydroelectric, navigation, flood control, and public water supply reservoirs of the southern United States. But as we have previously indicated, such measures are entirely unnecessary in the western United States because of the different breeding habits of the western species and because of physical differences in the type of reservoirs.

In Malaya, for a further example, no expenditures on malaria control have been necessary at the hydroelectric reservoir at Chenderoh, as the vector in that region is not a reservoir breeder.

### Species eradication

Up to 1940 little or no attention was given to the possibility of extirpating an entire vector species of mosquito in any area, or if the subject was broached, it was immediately dismissed by experts as a chimerical idea proposed by a foolish enthusiast having little regard for either practicability or costs. True, malaria had been extirpated from a few limited regions (as Penryn, California) by anti-anopheline measures, and it had disappeared for long periods from extensive regions in the United States, apparently due to better housing and better agriculture. But that any important vector species could be eradicated in any large area in tropical regions appeared to be impossible.

But to confound the sceptics, exactly this has happened, and it can and will happen again, given only the opportunity, the resources and skill, and the determination to do the job. Soper and Wilson[12, 13] have described the highly successful campaign carried on by the Republic of Brazil, assisted by the Rockefeller Foundation, which eliminated the very dangerous malaria vector *Anopheles gambiae* from Brazil in two years of steady, hard work; similar well-directed work has eliminated *Aedes aegypti* from entire cities and their surrounding territory. Soper and Wilson[13] are of the opinion that in the long run it is more practicable, more effective, and less expensive to eradicate a species in a limited area, and then carry on the relatively inexpensive measures to prevent its reintroduction, than it is to carry on a continuing campaign that aims merely at reducing the numbers of vectors below the point at which a disease can continue endemically.

Because of the importance of the ideas therein expressed, we quote directly from Soper and Wilson,[12] page 233, as follows:

> The campaign against *gambiae* differed from previous campaigns against malaria in that the objective was not simply the control of malaria in the local population, but the eradication of the vector in the entire area, not only to protect the local population against malaria, but also to prevent its spread to other regions. When the declared purpose of a campaign is the eradication of a species rather than the reduction in the incidence of disease caused by that species, the entire viewpoint of the service changes almost automatically. As long as evidence for the existence of the species continues to appear, the campaign has been a failure; there is no such thing as partial success in species eradication, one either achieves glorious success or dismal failure. Estimates of progress based on the traditional method of the malariologist, such as spleen rates, blood parasite rates, clinical attack rates, infant infection rates, become invalid and subordinated to the simple question, "Is the species under attack still present in the area being worked?"

These recent demonstrations that a species can be eradicated within a definite area open up new vistas of opportunities in tropical hygiene; sanitarians with imagination and a desire for as near an approach to perfection as is humanly possible will see in them both a challenge and an inspiration. After all, the greatest deterrent to the attainment of perfection is a compromise which is reasonably satisfactory.

AEDES AEGYPTI CONTROL*

The control of yellow fever has heretofore been based almost exclusively on the control of the principal urban vector, *Aedes aegypti*, and is therefore another example of species sanitation.

In recent years, while control of this principal vector has remained a basic item in the prevention of urban yellow fever, other factors have entered into the problem. One is the successful development of a protective vaccine by which large numbers of people can be immunized

* After the manuscript for this edition was completed, we received a copy of the important publication, Soper, F. L., Wilson, D. B., Luna, S., and Sa Antunes, W. The organization of permanent nation-wide anti-Aedes aegypti measures in Brazil (New York: The Rockefeller Foundation, 1943). This book will be most valuable to all persons working in the control of *Aedes aegypti*.

against the disease; the other is the recognition of a non-urban or "jungle" yellow fever (exactly the same disease) which is transmitted by a number of non-domestic tropical mosquitoes. While yellow fever vaccine has been used to protect civil populations in Brazil, especially in and near the jungle, at present it is used principally for the protection of military personnel which may expect to campaign in regions where yellow fever is known to occur. In the future it will probably be used extensively to protect civilians in potential yellow fever areas.

However, it is doubtful if there will be any more success in obtaining complete vaccination against yellow fever in susceptible civilians in an endemic area, or in areas subject to occasional epidemics, than we have had in obtaining complete vaccination against smallpox. Therefore we can expect that in urban areas in those parts of the world where *Aedes aegypti* occurs the control or even eradication of this insect will continue to be a basic sanitary measure, especially as it is also a vector of dengue, against which disease no immunizing agent has been developed so far.

*Aedes aegypti* is a mosquito which breeds almost exclusively in artificial containers of water, in and immediately adjacent to human habitations. Although it is usually referred to as an urban mosquito, it is found in rural districts within its normal range, but breeding is limited to close association with rural dwellings. An effective *aegypti* campaign may not confine itself to strictly urban areas, but must extend into the suburban regions, and may be required to extend into the more developed rural areas.

Since *Aedes aegypti* will breed in almost any type of container, on, under, or above ground, and either within or without houses or buildings occupied or used by man, efforts for its control must be based on infinite detail in painstaking search to find and correct its breeding places. Inspections must not only be thorough, but they must be repeated regularly throughout the breeding season, and corrections should be made as far as possible at the time of inspection. Inspections should also be made the basis of informational efforts, in an endeavor to educate the people as to the danger of permitting this species to breed and as to the methods of preventing its breeding.

Fortunately there is an appreciable public fear, at times even terror, of yellow fever and dengue, and therefore more attention to the demands of sanitary authorities will probably be manifested in most communities where these diseases are a possible threat; and as a rule public sentiment will be more apt to support prosecutions and other legal measures for persistent violation of notices to abate, than will be the case in communities where malaria is the important disease.

There are two main groups of thought as to basic methods in *Aedes aegypti* control. One group would concentrate first on finding and correcting all the principal foci of breeding, which are comparatively permanent collections of water such as cisterns, sumps, fire barrels, and shallow wells, and ignore at first what may be called "temporary" breeding places, such as tin cans, flower vases, buckets, gourds, or roof gutters. This group considers that it is the principal or "mother" foci which enable the mosquito to carry over from one season to the next; also, if the principal foci are eliminated, the number of adults available to reinfest the temporary or casual breeding places will be so reduced that breeding will eventually die out or be reduced to small numbers of little or no sanitary significance. Furthermore, with such a routine program in effect, if a case of yellow fever or dengue should be introduced into the community a rapid and intensive campaign upon the casual breeding places, supplemented by adult destruction (culicidal sprays), should completely prevent any outbreak.

It should be noted that the discovery and correction of all principal or "mother" foci of *aegypti* breeding may be quite difficult, as some of them will be well concealed and may be unobserved even by well-trained and experienced inspectors. The capture of adult mosquitoes as an index is required to localize the search for concealed permanent breeding places. In fact, the presence and relative numbers, or the complete absence, of adult *Aedes aegypti*, is the best criterion as to failure, partial results, or success in the campaign.

The other group of thought would make a simultaneous attack upon all possible types of breeding places and continue this program as a regular procedure. Obviously, this system predicates a large inspection and correction personnel from the beginning, a matter which presents certain practical difficulties.

Given sufficient time, energy, skill, and funds, complete eradication of *Aedes aegypti* in whole communities should be possible, as has been shown by the Yellow Fever Service in Brazil.[18]

The most logical sequence of procedures in an *Aedes aegypti* campaign (except under compulsion of an epidemic situation) appears to be the following:

1. Begin with a comparatively small and selected inspection personnel to find and correct the permanent ("mother foci") breeding places on a systematized schedule, using this initial period for the careful training of this personnel;
2. With this primary inspection-correction program under way, begin and intensively prosecute public education measures, by all available methods;
3. As soon as the primary personnel is sufficiently trained and experienced to be dependable, begin the training of an augmented inspection and correction force;
4. Put the additional inspection and correction force to work on cleaning up all temporary container breeding, at the same time carrying on an intensive adult destruction campaign by spraying methods;
5. Plan the measures necessary for the prevention of reinfestation of the area from outside sources and, as soon as success in eradication appears to be in sight, put them into effect.

While efficiently conducted campaigns of the general type indicated should be effective in controlling and even in extirpating *Aedes aegypti* in limited areas and should therefore eliminate urban yellow fever and dengue in such areas, we are unable to make any estimate of the practicability of the species sanitation of the vectors of jungle yellow fever, as it appears that sufficient precise data are not yet available for this purpose. Vaccination may have to remain the primary protection for some time to come for persons who must be near or in the jungle, especially for the reason that the situation is complicated by the presence of jungle animals which are reservoirs of the virus.

Likewise, no certain predictions as to the practicability of control or eradication of the other vector of dengue, *Aedes albopictus,* are possible at present. In view of the probability of extensive commitments for some time to come by military and occupational forces in the areas where this species exists, it appears strongly advisable that intensive studies be made of this species and the best methods for its control. However, we need not wait for needed research in these cases. Enough is known to enable us to make a successful attack upon this vector, though it probably will not be the most economical plan. In such circumstances the statement of Soper and Wilson (*loc. cit.*,[12] p. 233) is particularly applicable: "Under these conditions it was not feasible to lose time in making careful surveys or extensive preliminary studies of possible control methods; it seemed rather more expedient to learn how to get rid of *gambiae* by actually getting rid of *gambiae*."

SPECIES SANITATION OF PEST MOSQUITOES

Species sanitation was an idea developed in connection with the attack upon vector mosquitoes, but it is applicable to pest mosquitoes also. In fact, the campaigns against migratory salt-marsh mosquitoes are in effect a phase of species sanitation. It even extends to the matter of subspecies among pest mosquitoes.

Jobling[14] and several others have shown that our common domestic mosquito *Culex pipiens* is a complex of two subspecies, a zoophilous *C. pipiens pipiens* and an anthropophilous *C. pipiens molestus*. The former feeds principally on birds, rodents, and even frogs, and does not attack man; it hibernates, breeds preferably in relatively clear water of low or moderate organic content, and does not develop effectively in highly polluted water. The man-biting *C. p. molestus*, on the contrary, does not hibernate and develops readily and apparently by preference in foul water such as the contents of cesspools. As yet little practical use has been made of this information concerning *Culex pipiens*, but it does suggest strongly that there may be other pest mosquitoes which have subspecies of different characteristics and breeding habits; that it may be possible to ignore the subspecies which do not attack man; and that environmental changes may be effected which will minimize the numbers of man-biters or substitute for them a subspecies (or other species) which is of no importance as a nuisance.

## *NATURALISTIC CONTROL*

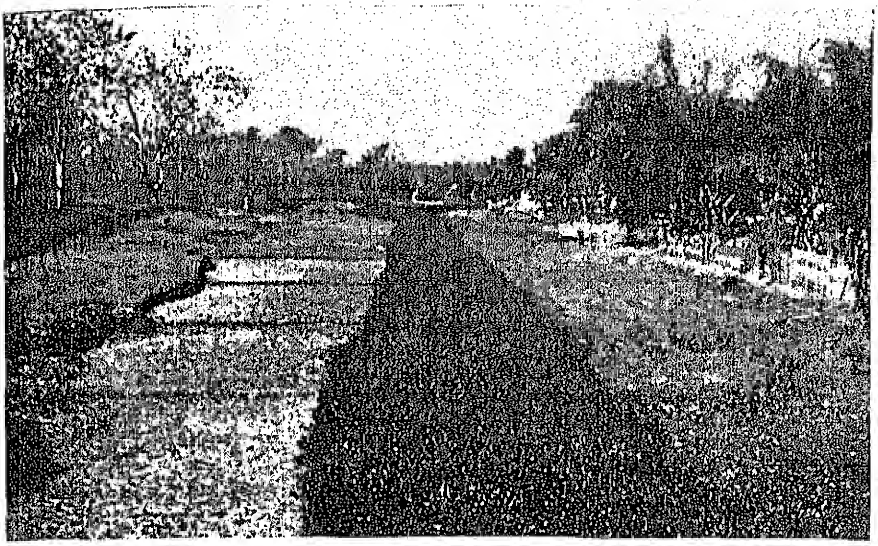
Practically every species of mosquito is to a greater or less extent limited in distribution and multiplication to certain types of breeding places, in which only it can breed in effective numbers. With some species the range in type of water for breeding is very narrowly restricted; in a few others, the range is fairly wide; and with the remainder, the type of breeding water has a fairly definite pattern for each species.

If we take cognizance of this natural restriction as to types of breeding places, and by relatively simple methods change, even very slightly in some cases, the character of such water or its surroundings, it becomes impossible for a species limited to such breeding water to continue to breed in appreciable numbers or at all, and it therefore ceases to be of importance numerically either as a disease vector or as a pest.

Any such change in the character of the breeding water or its immediate environment, when made as a planned measure of mosquito control, is termed a "naturalistic" control method, because it seeks to make changes in the natural conditions under which a particular mosquito species breeds, as distinguished from the mechanical or chemical methods of attack, such as drainage or larviciding. The method is ecological in concept and execution, rather than mechanistic.

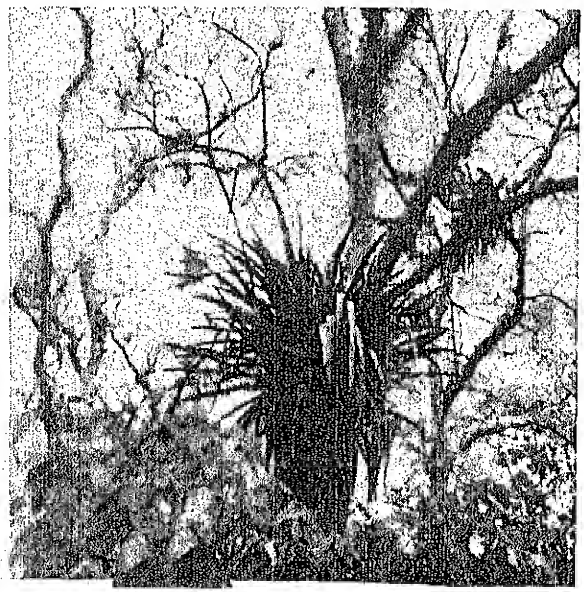
These naturalistic methods of mosquito control are deserving of much greater use than they have heretofore had. It is always easier to follow along in the rut and use the old dependable, standardized methods, than to exercise creative imagination to develop or adapt an ecological method of mosquito control. But progress comes from the latter type of work. However, methods are tested by results, and we must always keep in mind the idea that Ross[15] stated many years ago in regard to malaria control: "The proper policy is not the protection policy, nor the mosquito reduction policy, nor the quinine policy, but an opportunist policy which uses any weapon it can. Ultimately we have to frame our measures according to local feasibility."

H. R. Carter[16] was apparently one of the first to observe and record a naturalistic control measure, namely the variation of water levels in mill ponds, which acted as an anti-larval measure. In referring to changes in water level due to closing of mills over the week ends, Carter states: "These changes of elevation within a shorter time than the cycle of development of the mosquito should tend to prevent breeding. As the water falls it should leave some larvae stranded in the grass and behind drift, while the rise would expose them to some extent to fish, from which the shallow water and other conditions at the edges had protected them. Accidental changes should work to their disadvantage because it would be a change from protective conditions which they themselves had established." Fluctuation of water level is being used by the Tennessee Valley Authority as an important measure in the control of *Anopheles quadrimaculatus* in reservoirs along the Tennessee River.



*Courtesy Sir Malcolm Watson*

Figure 85. Dense shade provided by a planted hedge, to prevent breeding of *Anopheles minimus* in the central ditch of a rice field area



slightly in some cases, the character of such water or its surroundings, it becomes impossible for a species limited to such breeding water to continue to breed in appreciable numbers or at all, and it therefore ceases to be of importance numerically either as a disease vector or as a pest.

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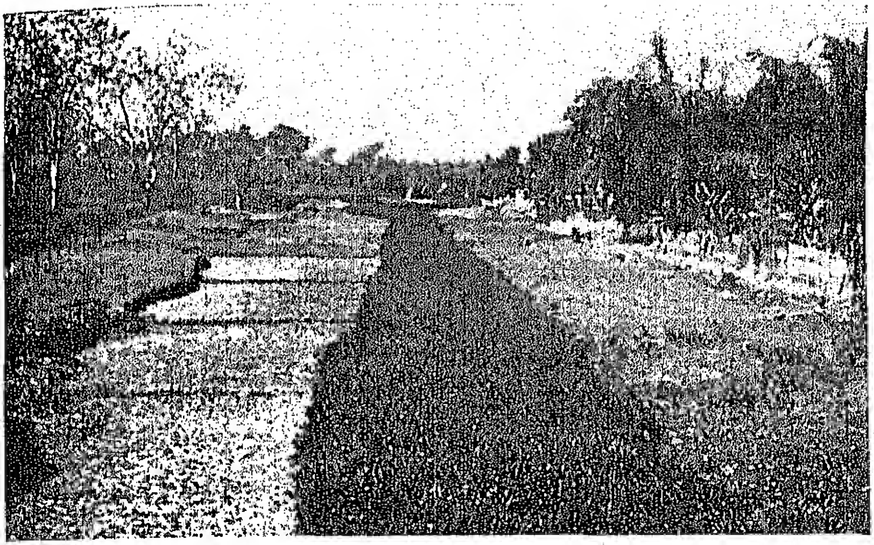
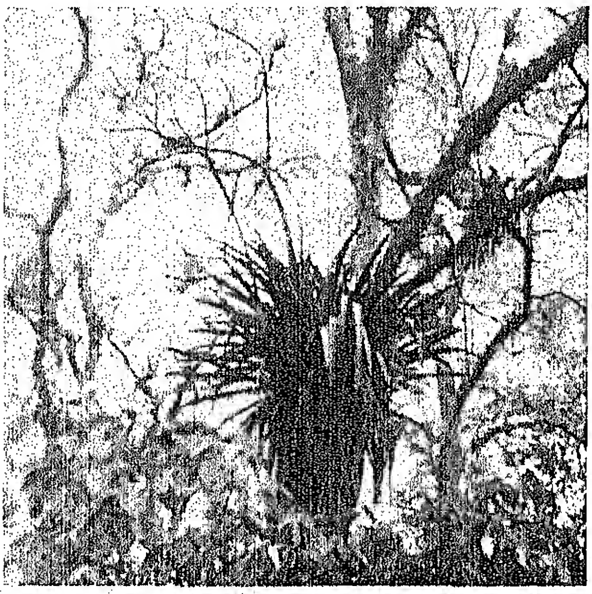


*Courtesy Sir Malcolm Watson*

Figure 85. Dense shade provided by a planted hedge, to prevent breeding of *Anopheles minimus* in the central ditch of a rice field area



*Courtesy The Rockefeller Foundation*

Figure 86. A bromeliad (epiphyte), an air plant attached to a tree. A typical breeding place for *Anopheles bellator* in Trinidad

Watson, Swellengrebel, and many others have contributed greatly to the development of naturalistic control methods, and Hackett[17] and others have assisted in systematizing the basic ideas of the measures.

A few examples of naturalistic methods of mosquito abatement will help to illustrate the use of this method.

*Anopheles maculatus*, a stream breeding vector of malaria in the hill areas of Malaya, is a sunlight breeder. Clearing of jungles, especially along streams and ditches, actually increased its breeding and the incidence of malaria. Stopping such clearing and encouraging the development of jungle shade along water courses helped to reduce the malaria transmitted by this species. The development of automatic flushing devices was a further step in the economical control of this mosquito. Automatic or manually operated stream and ditch flushing devices are also effective against the stream breeding *Anopheles minimus* (for example, in the Philippine Islands) and against the stream-bed breeding *A. culicifacies* in Ceylon.

Similarly, the planting of dense vegetation over breeding places and even shading such places with matting have been valuable in reducing the breeding of *Anopheles minimus* in India.[18] Coconut leaves have been used in like manner against *A. maculatus* in Malaya. In northern India dense shading of the irrigation channels and the drains in the rice fields, by plantings of dhuranta (*Duranta plumieri*) or lantana (*Lantana aculeata*) or basak (*Adhatoda vasica*), has effectively checked the breeding of the dangerous vector *Anopheles minimus*. In this region the still water of the rice paddies does not breed any vector anophelines.

Apparently the effect of such plantings is not the effect of shade in deterring the presence of *Anopheles minimus*, but the effect of dense shade in preventing the growth of vegetation in the water channels, for Thompson[19] has pointed out that in the perennial streams of Assam *Anopheles minimus* larvae are seldom found where the banks are bare of vegetation.

The breeding of *Anopheles minimus* in the shallow "Kachcha" wells[20] on tea estates in Assam and northern Bengal can be controlled by clearing so as to leave bare edges of soil at the water surface. Therefore with *Anopheles minimus* it is apparently the absence of marginal vegetation, rather than lack of sunlight, which is the critical factor.

If dense shading by hedges is to be used, it is important that ditch banks be raised sufficiently to enable the hedge to grow, for most shade shrubs will not grow in a waterlogged soil. Shade hedges should be pruned, preferably in the rainy season, to keep them neat and tidy.

Changing the salinity of water may have a profound effect upon the mosquito population of a body of water. By means of automatic flap gates, Hackett[21] eliminated the breeding of *Anopheles sacharovi (elutus)* in an extensive swamp area near Durazzo, Albania, introducing salt water at one end of the swamp and removing the displaced water near the opposite end, thus increasing the salinity of the water above the optimum for that species. A few years afterwards, through neglect, the water in this area was allowed to freshen, and *Anopheles sacharovi* reappeared promptly. Paradoxically, *A. sundaicus* in the mangrove swamp regions of Malaya could be controlled by lowering the salinity of the water, whereas in Java[22] an increase in the salinity of the water in the fish ponds drove out *A. sundaicus*, probably by changing the type of algae which grew in these ponds.

Years before the connection between *Anopheles* and malaria was known, the Italians recognized that a mixture of salt water and fresh water in the coastal marshes resulted in intense malaria. Control gates to keep out salt water in summer, erected by Zendrini at Viareggio in 1740 and still in use today, have minimized the breeding of the brackish water vectors. *A. sacharovi* and *A. labranchiae labranchiae*, and as a result these marshes and their vicinity have been healthy.[17]

An epidemic of malaria occurred at Falmouth[23] on Antigua in the West Indies, due to interference with natural tide action, so that the water on shoreward marshes freshened sufficiently to permit *Anopheles albimanus* to breed. Hurlbut,[24] in studying this problem in Porto Rico, found that *A. albimanus* could breed abundantly in certain brackish coastal lagoons, but that if these lagoons were opened up to normal tidal action, so as to bring the saline content up to an equivalent of over 50 per cent (preferably 75 per cent) of sea water, breeding ceased.

In Holland it is recognized that polders recently reclaimed from the sea are malarious, owing to the breeding of the vector species *A. labranchiae atroparvus*, a facultative brackish or fresh-water breeder, but with time these polders become freshened, and then *atroparvus* is replaced by the relatively harmless *A. messeae*, which seems to be able to over-breed competitively and supplant *atroparvus* in fresh water.

Many *Anopheles* species are quite fastidious and will not breed in foul water of high organic content. It is therefore possible to limit the breeding of such species by deliberately polluting the breeding water with decomposable organic matter. Cut vegetation of various types packed into breeding pools, so that it rots and fouls the water, will usually prevent *Anopheles* breeding, though it may result in a heavy infestation of certain culicine mosquitoes. To overcome this, the herbage should be packed into the water until it extends above and completely covers the water surface. In India it has been found that fouling with chopped cactus will prevent the breeding of *Anopheles culicifacies* from six to eight weeks.

The foregoing illustrations have been taken from the field of malaria control, for the reason that malaria control is probably one of the most intricate and involved of all the phases of mosquito abatement. The variability of the problem on a world-wide basis is certainly considerable; in any particular region successful control at reasonable cost can only be obtained by recognizing this variability, approaching the study of the problem with an open mind to determine all the factors in any local situation, and then applying the appropriate control measure or perhaps devising new control measures specifically adapted to the species of mosquito involved and the environmental conditions under which it exists.

Control efforts directed against a particular dangerous species of mosquito and naturalistic methods of control of such species have been more definitely used in the prevention of malaria than in any other aspect of mosquito abatement. Naturalistic methods can, however, be used against any particular species of mosquito if only sufficient study is given to the ecology of each species to determine favorable and unfavorable breeding conditions. But in the field of pest mosquito abatement, while some progress has been made, less use of naturalistic control methods has been obtained, though this plan of attack offers great opportunities for economies and effectiveness. With pest mosquito problems, the direct attack upon the important species (species sanitation) by the methods appropriate to that species is certainly obvious. What is less obvious is that in many cases more ingenuity could be used in adapting measures which effect an environmental change unfavorable to the breeding of a particular pest mosquito. There is no reason why naturalistic control methods cannot produce as good results in pest mosquito control as in the control of malaria vectors. Drainage and the use of oil or other larvicides will probably remain the dependable control methods, but imagination and careful study certainly should develop naturalistic methods of pest mosquito abatement which will either reduce the cost of drainage and oiling or greatly enhance their effectiveness. For any specific abatement problem such studies should yield advantageous results.

For example, the naturalistic method of controlled reflooding and redraining should effect greater efficiency and ultimately marked economy in the abatement of the various salt-marsh mosquitoes, such as *Aedes sollicitans*, *A. taeniorhyncus*, *A. dorsalis*, *A. caspius*, and *A. squamiger*. Perhaps a modification of this method might be applied successfully to the abatement of such flood-water types as *Aedes vexans* and *Aedes aldrichi*. Studies are surely needed to develop successful naturalistic methods of attack upon other pests, such as *Mansonia perturbans* and *Psorophora confinnis*.

As an illustration of the variability of the mosquito control problem, we have prepared APPENDIX A, PART I (page 361), in which are listed geographically a considerable number of the anopheline mosquitoes with their more usual or typical breeding places, and the regions in which they are either important (primary) or secondary (occasional, or very localized) vectors of malaria.

We have not attempted to prepare a similar table to include all the vectors of other mosquito-transmitted diseases, for the reason that our knowledge of the biology and ecology of many of these species is too meager and inexact for the purpose. However, in APPENDIX B (page 367) we have listed the known vectors of yellow fever, dengue, filariasis, and encephalitis, with some information as to the approximate geographical ranges of these species.

As a guide to the subject of species sanitation in the field of malaria control, we have prepared and present as PART II of APPENDIX A a chart showing the important vector *Anopheles* throughout the world, grouped geographically and according to the principal types of breeding places, with suggestions as to appropriate control measures.

The basis for this chart was provided in a small chart devised by Sir Malcolm Watson (not published), which we have greatly enlarged and extended. We have used it for a year or more in teaching medical and sanitary officers in the Navy and Army of the United States. It has passed through a number of revisions during this time, and we are especially indebted to Sir Rickard Christophers and Sir Malcolm Watson for so generously taking a great deal of time to advise us as to the Indian and Far East anophelines, and to Stanley B. Freeborn and many others who have offered valued suggestions.

A generalized presentation of this type suffers from many difficulties, of which not the least is the lack of precision in regard to details relating to many species. But its advantages as an overall view of a very important matter are so great that they outweigh the admitted faults and limitations. The chart probably contains some errors, but we hope that they are errors of omission only.

More precise charts can be constructed along somewhat similar lines for malaria vectors in limited regions.

Charts with the same general purpose can also be constructed eventually for the important vectors of mosquito-transmitted diseases other than malaria.

In APPENDIX C (page 371) we have presented the classification of mosquito abatement methods originally devised by Russell and Hackett,[25] which we have modified and extended to cover pest mosquitoes as well as malaria vectors.

In APPENDIX D (page 374) we present material on the identification of mosquito genera and species, and the use of identification keys. This we have endeavored to simplify so that it will help the person who has not been technically trained in systematic entomology to gain at least an insight into the methods of identification of mosquitoes. The systematists will probably scoff at it, but we did not prepare it for their purposes. If it will help doctors, engineers, and sanitarians, our purpose is attained.

In APPENDIX E (page 390) are listed the more important books and technical articles relating to mosquito classification, identification, biology, and ecology, grouped according to main geographical regions so as to guide anyone working in a particular area to the more important material dealing with the mosquitoes of that region.

In conclusion, we state as our belief that there is no fool-proof formula or infallible method for mosquito abatement. There is much that we know concerning mosquito abatement methods, but probably much more that we do not know. In every new situation we should first define the problem by careful and adequate field studies and then apply the indicated appropriate abatement methods; but we should keep an open mind concerning methods and scrutinize them and their results with a scientific scepticism which will not be satisfied with less than the nearest approach to perfection possible. And in any long existing situation probably an even more sceptical attitude may be valuable, for it is possible that an idea which has stood unchallenged for a generation may be wrong at least in part, having not kept pace with the accretions of new information.

Continued research is necessary in mosquito control but it must not be limited to the laboratories of the universities. The true place of research is on the job: every hour and every day in practical work mosquito abatement people in all ranks have opportunity to make observations of value, and by ingenious adaptation improve methods of attack on these enemies of man. Mosquito control still has not only the fascination and intense interest of exploring the unknown and of giving opportunity for the trial of new ideas, but it also has the satisfaction of contributing greatly to the health, comfort, and prosperity of mankind.

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Appendix A

# PART I. THE PRINCIPAL ANOPHELINES OF THE WORLD

*Their Typical Breeding Places and the Regions Where They Occur*

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| NORTH AMERICA, CENTRAL AMERICA, AND WEST INDIES | | |
| *A. albimanus* Wiedemann | Southeast Texas, coastal Mexico, Central America, West Indies | Sunlit swamps, pools, lakes, fresh or brackish |
| *A. aquasalis* Curry | Nicaragua, Panama, Trinidad, Lesser Antilles | Brackish tidal swamps, rice fields |
| *A. bellator* Dyar and Knab | Trinidad | Bromeliads |
| *A. crucians crucians* Wiedemann | Southern and eastern United States? Mexico? West Indies? | Fresh water pools |
| *A. darlingi* Root | British Honduras, Guatemala | Lagoons, overflows, ponds, shaded, with vegetation |
| *A. hectoris* Giaquinta Mira | Mexico? Guatemala? above 4,000 feet | Pools, wells, ponds, troughs |
| *A. maculipennis aztecus* Hoffmann | Mexico? | Pools, ditches |
| *A. maculipennis freeborni* Aitken | Western United States, northwest Mexico | Clean, sunlit, fresh seepage water |
| *A. pseudopunctipennis pseudopunctipennis* Theobald | Southern and western United States? Mexico? Central America? | Sunlit water, algae |
| *A. pseudopunctipennis franciscanus* McCracken | Southwestern United States? northern Mexico? | Sunlit pools along receding streams, algae |
| *A. punctimacula* Dyar and Knab | Mexico, Central America, Trinidad | Shaded swamps, pools, streams |
| *A. punctipennis* (Say) | North America? | Margins of streams, pools, springs, shaded |

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| *A. vestipennis* Dyar and Knab | Honduras? | Shaded streams, pools, ponds |
| | SOUTH AMERICA | |
| *A. albimanus* Wiedemann | Colombia, Ecuador, Venezuela | Sunlit swamps, pools, lakes, fresh or brackish |
| *A. albitarsis* Lynch Arribalzaga | Northeast Argentina, Brazil, Guianas? Paraguay, Venezuela? | Large ponds, swamps, with vegetation |
| *A. aquasalis* Curry | Brazil | Brackish tidal swamps, rice fields |
| *A. argyritarsis* Robineau-Desvoidy | Brazil? Argentina? | Pools, seepages |
| *A. darlingi* Root | Venezuela, Guianas, Brazil, Argentina | Lagoons, overflows, ponds, shaded, with vegetation |
| *A. pseudopunctipennis pseudopunctipennis* Theobald | Argentina, Chile | Sunlit water, algae |
| | EUROPE | |
| *A. algeriensis* Theobald | Italy? Macedonia? | Marshes, sluggish streams, much vegetation |
| *A. labranchiae atroparvus* van Thiel | Holland, Germany, northeast Italy, Spain, Portugal, Balkans | Brackish or fresh water swamps, pools |
| *A. labranchiae labranchiae* Falleroni | Italy, southern Spain, Sicily, Sardinia, Corsica, Dalmatian coast | Coastal marshes, brackish; rice fields, upland streams |
| *A. maculipennis maculipennis* Meigen | Hungary, Roumania, Macedonia, southern Russia | Fresh water pools, in hill areas |
| *A. melanoon melanoon* Hackett | Italy? | Marshes, rice fields |
| *A. messeae* Falleroni | Roumania | Lakes, ponds, marshes |
| *A. sacharovi* Favr | Italy, Sardinia, Balkans, central Russia | Coastal marshes (brackish), inland marshes (fresh), in sunlight |
| *A. superpictus* Grassi | Spain, Italy, Greece, Jugoslavia, Albania, Macedonia, Bulgaria, Thrace | Stream bed pools, rocky or gravelly, hill or mountain areas |
| | AFRICA | |
| *A. algeriensis* Theobald | Algeria? Egypt? | Marshes, sluggish streams, much vegetation |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
| --- | --- | --- |
| *A. claviger* (Meigen) (= *bifurcatus*) | Northern Africa? | Marshes, rock pools |
| *A. d'thali* Patton | Egypt? Somaliland? Sudan? | Stream pools, springs, wells |
| *A. funestus funestus* Giles | Tropical Africa | Swamps, weedy streams, ponds, seepages |
| *A. gambiae* Giles | Tropical Africa | Small pools in direct sunlight. Occasionally in artificial containers. Highly domestic. A dark variety in brackish water |
| *A. hancocki* Edwards | *Central Africa (west)?* | *Grassy pools, ditches,* swamps |
| *A. hargreavesi* Evans | Central Africa (west)? | Swamps, streams, with vegetation |
| *A. labranchiae labranchiae* Falleroni | Northwest coastal Africa | Coastal marshes, brackish; rice fields, upland streams |
| *A. marshallii gibbinsi* Evans | Uganda? | Slow, shallow streams, drains, with vegetation, sunlit |
| *A. moucheti moucheti* Evans | Central Africa? | Margins of rivers, streams, pools, swamps; vegetation |
| *A. moucheti nigeriensis* Evans | Southern Nigeria? | Swamps, vegetation |
| *A. multicolor* Cambouliu | North Africa, Egypt, Sudan | Saline desert water; pools, drains, shallow wells |
| *A. nili* (Theobald) | Central and southern Africa? Mozambique? | Sides of streams, vegetation, shaded |
| *A. pharoensis* Theobald | Sudan, upper Egypt, central and southern Africa? | Swamps, rice fields, vegetation |
| *A. pretoriensis* (Theobald) | Central and southeastern Africa? | Small pools without shade or vegetation |
| *A. sergenti* (Theobald) | Algeria? Tunisia? Egypt | Rice fields, borrow pits, ditches, with vegetation |
| | ASIA | |
| *A. aconitus* Dönitz | India? Burma? Thailand? Malaya? Indo-China? | Swamps, ponds, pools, rice fields, ditches |
| *A. annularis* van der Wulp (= *fuliginosus* Giles) | India? Burma? southern China? Formosa? Thailand? Indo-China? Malaya? | Ponds (vegetation), streams, ditches, lakes (marginal) |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| *A. vestipennis* Dyar and Knab | Honduras? | Shaded streams, pools, ponds |
| | SOUTH AMERICA | |
| *A. albimanus* Wiedemann | Colombia, Ecuador, Venezuela | Sunlit swamps, pools, lakes, fresh or brackish |
| *A. albitarsis* Lynch Arribalzaga | Northeast Argentina, Brazil, Guianas? Paraguay, Venezuela? | Large ponds, swamps, with vegetation |
| *A. aquasalis* Curry | Brazil | Brackish tidal swamps, rice fields |
| *A. argyritarsis* Robineau-Desvoidy | Brazil? Argentina? | Pools, seepages |
| *A. darlingi* Root | Venezuela, Guianas, Brazil, Argentina | Lagoons, overflows, ponds, shaded, with vegetation |
| *A. pseudopunctipennis pseudopunctipennis* Theobald | Argentina, Chile | Sunlit water, algae |
| | EUROPE | |
| *A. algeriensis* Theobald | Italy? Macedonia? | Marshes, sluggish streams, much vegetation |
| *A. labranchiae atroparvus* van Thiel | Holland, Germany, northeast Italy, Spain, Portugal, Balkans | Brackish or fresh water swamps, pools |
| *A. labranchiae labranchiae* Falleroni | Italy, southern Spain, Sicily, Sardinia, Corsica, Dalmatian coast | Coastal marshes, brackish; rice fields, upland streams |
| *A. maculipennis maculipennis* Meigen | Hungary, Roumania, Macedonia, southern Russia | Fresh water pools, in hill areas |
| *A. melanoon melanoon* Hackett | Italy? | Marshes, rice fields |
| *A. messeae* Falleroni | Roumania | Lakes, ponds, marshes |
| *A. sacharovi* Favr | Italy, Sardinia, Balkans, central Russia | Coastal marshes (brackish), inland marshes (fresh), in sunlight |
| *A. superpictus* Grassi | Spain, Italy, Greece, Jugoslavia, Albania, Macedonia, Bulgaria, Thrace | Stream bed pools, rocky or gravelly, hill or mountain areas |
| | AFRICA | |
| *A. algeriensis* Theobald | Algeria? Egypt? | Marshes, sluggish streams, much vegetation |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| *A. claviger* (Meigen) (= *bifurcatus*) | Northern Africa? | Marshes, rock pools |
| *A. d'thali* Patton | Egypt? Somaliland? Sudan? | Stream pools, springs, wells |
| *A. funestus funestus* Giles | Tropical Africa | Swamps, weedy streams, ponds, seepages |
| *A. gambiae* Giles | Tropical Africa | Small pools in direct sunlight. Occasionally in artificial containers. Highly domestic. A dark variety in brackish water |
| *A. hancocki* Edwards | Central Africa (west)? | Grassy pools, ditches, swamps |
| *A. hargreavesi* Evans | Central Africa (west)? | Swamps, streams, with vegetation |
| *A. labranchiae labranchiae* Falleroni | Northwest coastal Africa | Coastal marshes, brackish; rice fields, upland streams |
| *A. marshallii gibbinsi* Evans | Uganda? | Slow, shallow streams, drains, with vegetation, sunlit |
| *A. moucheti moucheti* Evans | Central Africa? | Margins of rivers, streams, pools, swamps; vegetation |
| *A. moucheti nigeriensis* Evans | Southern Nigeria? | Swamps, vegetation |
| *A. multicolor* Cambouliu | North Africa, Egypt, Sudan | Saline desert water; pools, drains, shallow wells |
| *A. nili* (Theobald) | Central and southern Africa? Mozambique? | Sides of streams, vegetation, shaded |
| *A. pharoensis* Theobald | Sudan, upper Egypt, central and southern Africa? | Swamps, rice fields, vegetation |
| *A. pretoriensis* (Theobald) | Central and southeastern Africa? | Small pools without shade or vegetation |
| *A. sergenti* (Theobald) | Algeria? Tunisia? Egypt | Rice fields, borrow pits, ditches, with vegetation |
| | ASIA | |
| *A. aconitus* Dönitz | India? Burma? Thailand? Malaya? Indo-China? | Swamps, ponds, pools, rice fields, ditches |
| *A. annularis* van der Wulp (= *fuliginosus* Giles) | India? Burma? southern China? Formosa? Thailand? Indo-China? Malaya? | Ponds (vegetation), streams, ditches, lakes (marginal) |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| *A. barbirostris barbirostris* van der Wulp | India? Burma? Thailand? China? Indo-China? Malaya? | Streams, ponds, pools, rice fields, brackish swamps, usually shaded |
| *A. culicifacies* Giles | Ceylon, India, Burma, Thailand, south Arabia | Stream bed pools, pools of all types |
| *A. fluviatilis* James (= *listoni* Liston) | India (above 1,000 feet elevation in south India), Burma, Thailand? | Stream edges, stream pools, ditches |
| *A. gambiae* Giles | Arabian peninsula | Small pools in direct sunlight |
| *A. hyrcanus nigerrimus* Giles | Malaya? Burma? Thailand? China? Indo-China? | Rice fields, canals, impounded water |
| *A. hyrcanus sinensis* Wiedemann | Burma? Indo-China? China? Korea? Japan? Formosa? | Rice fields, swamps, ponds |
| *A. jeyporiensis jeyporiensis* James | Eastern India? | Streams, lakes, ponds |
| *A. jeyporiensis candidiensis* Koidzumi | Tonkin? | Ditches |
| *A. kochi* Dönitz | India? Burma? Malaya? | Small, muddy pools; ditches |
| *A. leucosphyrus leucosphyrus* Dönitz | India? Burma? Malaya? Indo-China? | Rocky pools |
| *A. labranchiae atroparvus* van Thiel | Siberia, Mongolia, north Manchukuo | Brackish and fresh water swamps, pools |
| *A. maculatus maculatus* Theobald | Malaya, Burma, Indo-China, Thailand, south China? | Streams, river and stream bed pools, seepages, in sunlight |
| *A. minimus* Theobald | Eastern and northern India, Assam, Burma, Thailand, Indo-China, southern China, Formosa | Clear, sunlit streams, ditches, springs, pools, with vegetation |
| *A. pallidus* Theobald | India? Ceylon? Burma? | Ponds, rice fields, ditches |
| *A. pattoni* Christophers | Japan, China north of 30° N. | Stream bed pools, rain water pools |
| *A. philippinensis* Ludlow | Bengal, Malaya? Thailand? Burma? Indo-China? | Pools, ponds, swamps, ditches, rice fields |
| *A. pulcherrimus* Theobald | Mesopotamia? Iran? Turkestan? India? | Swamps, pools, rice fields |
| *A. ramsayi* Covell | India? Burma? Thailand? | Swamps, rain pools |
| *A. sacharovi* Favr | Transcaucasia, Iran, Iraq, west China | Brackish and fresh water swamps, pools |
| *A. sergenti* (Theobald) | Palestine, Syria? northwest India? | Rice fields, borrow pits, ditches, with vegetation |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
|---|---|---|
| *A. splendidus* Koidzumi | India? China? Thailand? Formosa? | Small pools, with algae, vegetation |
| *A. stephensi stephensi* Liston | Arabia, Iraq, Iran, India, Burma | Wells, cisterns, artificial containers (urban) |
| *A. subpictus subpictus* Grassi (= *rossi* Giles) | India? Malaya? | Any water, fresh or brackish or polluted |
| *A. sundaicus* (Rodenwaldt) | Bengal, Malaya, Indo-China, Burma? Thailand? | Brackish water swamps, lagoons, ponds |
| *A. superpictus* Grassi | Anatolia, Cyprus, Caucasus, Transcaucasia, Palestine, Syria, Mesopotamia, Iran, northwest India, southwest Siberia | Stream bed pools, rocky or gravelly, hill or mountain areas |
| *A. tessellatus* Theobald | Indo-China? | Stream margins, rice fields, pools |
| *A. turkhudi* Liston | Arabia? Iran? India? | Rain water pools, stream bed pools |
| *A. umbrosus* (Theobald) | Malaya, eastern India, Burma, Indo-China | Jungle pools and swamps, mangrove swamps, deep shade |
| *A. vagus vagus* Dönitz | India? | Small pools, in and about villages |
| *A. varuna* Iyengar | India? Burma? | Pools, ditches, wells |
| EAST INDIES AND PHILIPPINE ARCHIPELAGOES | | |
| *A. aconitus* Dönitz | Sumatra? Java? Borneo? Celebes? | Swamps, ponds, pools, rice fields, ditches |
| *A. annularis* van der Wulp (= *fuliginosus* Giles) | Sumatra? Java? Philippines? | Ponds (vegetation), streams, ditches, lakes (marginal) |
| *A. barbirostris barbirostris* van der Wulp | Sumatra? Java? Borneo? Celebes? New Guinea? Philippines? | Streams, ponds, pools, rice fields, brackish swamps, usually shaded |
| *A. hyrcanus nigerrimus* Giles | Sumatra? Java? Borneo? Celebes? Philippines? | Rice fields, canals, impounded water |
| *A. kochi* Dönitz | Sumatra? Java? Borneo? Moluccas? Philippines? | Small muddy pools, ditches |
| *A. leucosphyrus leucosphyrus* Dönitz | Sumatra? Java? Borneo? Philippines? | Rocky pools |
| *A. maculatus maculatus* Theobald | Netherlands Indies? Philippines? | Streams, river and stream bed pools, seepages, in sunlight |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region of malaria transmission | Typical breeding places |
| --- | --- | --- |
| *A. mangyanus* (Banks) | Philippine Islands | Shallow streams in hill or mountain areas |
| *A. minimus flavirostris* (Ludlow) | Philippine Islands | Shaded streams, ditches, pools |
| *A. philippinensis* (Ludlow) | Philippine Islands? | Pools, ponds, swamps, ditches, rice fields |
| *A. subpictus subpictus* Grassi (= *rossi* Giles) | Netherlands Indies? Celebes, New Guinea? | Any water, fresh or brackish or polluted |
| *A. subpictus indefinitus* (Ludlow) | Philippine Islands? | Sunlit streams, ditches, pools, wells, sometimes brackish |
| *A. sundaicus* (Rodenwaldt) | Sumatra, Borneo, Java | Brackish water swamps, lagoons, ponds |
| *A. umbrosus* (Theobald) | Sumatra, Java, Borneo, Celebes | Jungle pools and swamps, mangrove swamps, deep shade |
| *A. vagus limosus* King | Philippine Islands? | Muddy open pools, muddy ditches |
| AUSTRALIA, MELANESIA, POLYNESIA | | |
| *A. annulipes annulipes* Walker | Australia? Tasmania? | Shallow grassy pools, marshes, streams, sometimes brackish water |
| *A. bancrofti* Giles | New Guinea? northern Australia? | Shallow, slow moving water, with vegetation |
| *A. punctulatus punctulatus* Dönitz | New Guinea, islands west of Celebes and Timor, Melanesia north of 20° S., west of 170° E.; northern Australia | Open rain pools, stream margins, in sunlight |
| *A. punctulatus moluccensis* (Swellengrebel and Swellengrebel de Graaf) | Moluccas, New Britain, New Guinea, New Hebrides, Admiralty Islands, northern Australia | Any water, fresh or brackish, clear or polluted |

Note: A question mark indicates doubtful importance in a particular region.

| Species | Region | Typical breeding places |
|---|---|---|
| *Aedes punctocostalis* | West Africa | Water in temporary ground pools |
| *Aedes triseriatus* | Eastern United States | Water in tree holes |
| *Aedes geniculatus* | Asia Minor | Water in tree holes |
| *Aedes albopictus* | North Australia, Madagascar, Netherlands Indies, Fiji, Japan, China coast, Indo-China, Thailand, Philippine Islands, India, Ceylon, Hawaii, New Guinea | Water in artificial containers; tree holes, leaf axils, rock pools, in wooded areas |
| *Culex thalassius* | West, south, and east Africa | Water in crab holes, ground pools |

Note: At least a dozen other species of mosquitoes have been proven experimentally to be good incubators for the virus of yellow fever, but are not considered to be transmitters.

## PART II. VECTORS OF DENGUE

| | | |
|---|---|---|
| *Aedes aegypti* | Southern United States, Central America, Mexico, West Indies, tropical and sub-tropical South America, tropical and sub-tropical Africa, including the Nile valley, Mediterranean basin, India, Indo-China, New Guinea, Celebes, Queensland, Pacific Islands | Water in all kinds of artificial containers, in close association with human habitations |
| *Aedes albopictus* | North Australia, Madagascar, Netherlands Indies, Fiji, Japan, China coast, Indo-China, Thailand, Philippine Islands, India, Ceylon, Hawaii, New Guinea | Water in artificial containers; tree holes, leaf axils, rock pools, in wooded areas |
| *Armigeres obturans* | Formosa, Japan, south and central China, India, Ceylon, Borneo, New Guinea, Queensland | Polluted water and water in artificial containers |

## PART III. VECTORS OF FILARIASIS (*WUCHERERIA BANCROFTI*)

| | | |
|---|---|---|
| *Culex quinquefasciatus* (= *Culex fatigans*) | South China, Foochow, Woosung, Hongkong, Formosa, Hoko Islands, Celebes, India, Netherlands Indies, Egypt, Brazil, Pa- | Water in artificial containers, especially in sewage or organic contaminated water about human habitations, usu- |

PART III (cont.)

| Species | Region | Typical breeding places |
|---|---|---|
| | cific Islands, Australia, West Indies, Philippine Islands. Tropical and subtropical regions | ally covered or well shaded |
| *Culex pipiens pallens* | Central China, Foochow, Woosung, Shanghai, Japan, Egypt (Cairo) | Similar to *Culex quinquefasciatus* |
| *Anopheles hyrcanus sinensis* | Yangtze valley, Amoy, Woosung, Foochow, Soochow, Shanghai, Hongkong, Thailand, Burma, Malaya | Rice fields, ponds, ditches, canals |
| *Aedes scutellaris*[1] (= *Aedes variegatus*) | Pacific Islands, exclusive of Hawaii | Water in artificial containers, tree holes, etc. |
| *Aedes togoi* | Foochow, Hongkong, Japan | Rock pools near sea shore |
| *Anopheles subpictus* (= *Anopheles rossi*) | India | Any water, clean or polluted, fresh or brackish |
| *Anopheles amictus* | North Queensland | Pools, clean or polluted |
| *Anopheles funestus* | Tropical Africa | Swamps, weedy streams, seepage |
| *Anopheles maculatus* | Hongkong, Foochow | River and stream bed pools and seepages, in sunlight |
| *Anopheles minimus* | Hongkong, Foochow | Clear sunlit streams, ditches, springs and pools, with vegetation |
| *Anopheles gambiae* | Tropical and south Africa | Small pools in direct sunlight, occasionally in artificial containers; highly domestic |
| *Culex tritaeniorhynchus* | Woosung, Foochow, Shanghai | Water in ground pools |
| *Culex vagans* | Shanghai | Water in artificial containers |
| *Culex fuscanus* | Shanghai | Water in artificial containers |
| *Culex vorax* | Shanghai | Water in artificial containers |

Note: Well over 80 species of mosquitoes (*Culex, Anopheles, Aedes,* and *Mansonia*) are known to be transmitters of *Wuchereria bancrofti* infection.

Note: *Wuchereria malayi* parasitizes man, causing elephantiasis of the upper extremities, in the Netherlands Indies, Celebes, Chekiang Province, Indo-China, New Guinea, and Japan. Various mosquitoes of the genus *Mansonia* (*Mansonioides*) are transmitters. Larvae of these mosquitoes attach themselves to aquatic vegetation, e.g., *Pistia*.

[1] This day-biting species transmits the disease in areas where *Wuchereria bancrofti* does not exhibit a nocturnal periodicity.

## PART IV. VECTORS OF EPIDEMIC (VIRUS) ENCEPHALITIS

| Species | Region | Typical breeding places |
|---|---|---|
| *Culex tarsalis* | Pacific Coast, Texas, western United States (St. Louis and Western Equine types; fully incriminated in field and laboratory) | All types of sunlit fresh-water pools and drains, particularly with organic pollution |

Note: The following species have transmitted the several viruses experimentally in the laboratory, and are possible (some of them probable) vectors under appropriate conditions.

St. Louis virus only—*Culex pipiens* (*molestus?*), *Culex pipiens pallens, Culex coronator, Culiseta incidens, Culiseta inornata*

Eastern Equine virus only—*Aedes atropalpus, Aedes triseriatus, Aedes cantator*

Western Equine virus only—*Aedes dorsalis* (fresh-water form), *Aedes albopictus*

Eastern Equine virus and Western Equine virus—*Aedes aegypti, Aedes sollicitans, Aedes sylvestris*

St. Louis virus and Western Equine virus—*Aedes lateralis, Aedes taeniorhyncus, Aedes nigromaculis*

St. Louis virus, Western Equine virus, Eastern Equine virus—*Aedes vexans*

## Appendix C

# A CLASSIFICATION OF MOSQUITO ABATEMENT METHODS

### AGAINST AQUATIC STAGES

I. *MECHANICAL*

- a. Drainage
  1. Open
  2. Subsurface
  3. Vertical
- b. Pumping
  1. Surface water
  2. Subsurface (well) water
- c. Diversion of water
- d. Channeling of streams and sloughs
- e. Filling in low areas
- f. Restriction or control of excessive use or needless abuse of irrigation water
- g. Miscellaneous
  1. Screening or mosquito-proofing cisterns, wells, and water containers
  2. Removal or destruction of unnecessary artificial water containers
  3. Removal of protective vegetation or floatage
  4. Repair of leaks or defects in water supply, plumbing, or drainage systems
  5. Tree surgery

### AGAINST ADULT MOSQUITOES

I. *MECHANICAL*

- a. Screens
  Nets
  Special clothing
- b. Deterrents
  Fans and punkahs
  Exposure to wind
- c. Trapping
  1. Baited traps
  2. Light traps
- d. Hand catching and killing
  1. Active season killing
  2. Winter killing
- e. Removal of houses or villages to sites beyond flight range

Note: This classification is modified from Russell, P. F., and Hackett, L. W. A new classification of mosquito control measures. Acta Conventus Tertii de Tropicis atque Malaria Morbis, Part 2, 96–99. Amsterdam: Societas Neerdlandica Medicinae Tropicae, 1938.

AGAINST AQUATIC STAGES

II. *TOXIC*

- a. Petroleum derivative oils
  - 1. Direct refinery products
  - 2. Treated oils, for increased toxicity or increased spreading capacity
  - 3. Reclaimed waste oils
- b. Larvicides
  - 1. Emulsions
    - Pyrethrum
    - Cresylic or phenolic acids
  - 2. Soluble poisons
  - 3. Solids (powdered)
    - Paris green
    - Phenothiazine
    - Gesarol (DDT)
- c. Toxic gases

III. *NATURALISTIC*

- a. Chemical
  - 1. Changing salt (NaCl) content of water
    - Salinification
    - Freshening
  - 2. Pollution
    - with decaying vegetation (herbage packing)
    - with sewage or wastes
  - 3. Stagnating
- b. Physical
  - 1. Drying by agricultural use or by special plantings
  - 2. Natural fills (silting)
  - 3. Setting water in motion
  - 4. Intermittent drying
  - 5. Fluctuating water levels
  - 6. Flushing or sluicing
    - Automatic
    - Hand operated
  - 7. Constant level flooding
  - 8. Controlled reflooding and redraining
  - 9. Agitation
    - Volumetric (see 3)
    - Surface, especially by wind
  - 10. Shading to exclude sunlight
  - 11. Clearing to expose to sunlight
  - 12. Muddying

AGAINST ADULT MOSQUITOES

II. *TOXIC*

- a. Sprays
- b. Fumigants
- c. Chemical repellents

III. *NATURALISTIC*

- a. Chemical
  - 1. Administration of drugs like sulphur which cause odorous perspiration
  - 2. Creating repellent barriers of odorous plants
- b. Physical
  - 1. Clearing, destruction, or removal of shelter
  - 2. Creation of plant barriers to flight
  - 3. Rendering dwellings, especially bedrooms, unattractive to mosquitoes

AGAINST AQUATIC STAGES

c. Biological
   1. Introduction of natural enemies
      Predatory fish
      Other aquatic predators
   2. Changing flora and fauna to unsuitable or competitive types
   3. Elimination or destruction of aquatic food supplies (copper sulphate as an algicide)

AGAINST ADULT MOSQUITOES

c. Biological
   1. Introduction of natural enemies
      Predatory crepuscular birds, etc.
      Parasites
   2. Deviation by animals
   3. Minimizing available harborage for winter hibernation

## Appendix D

# IDENTIFICATION OF MOSQUITOES—USE OF KEYS

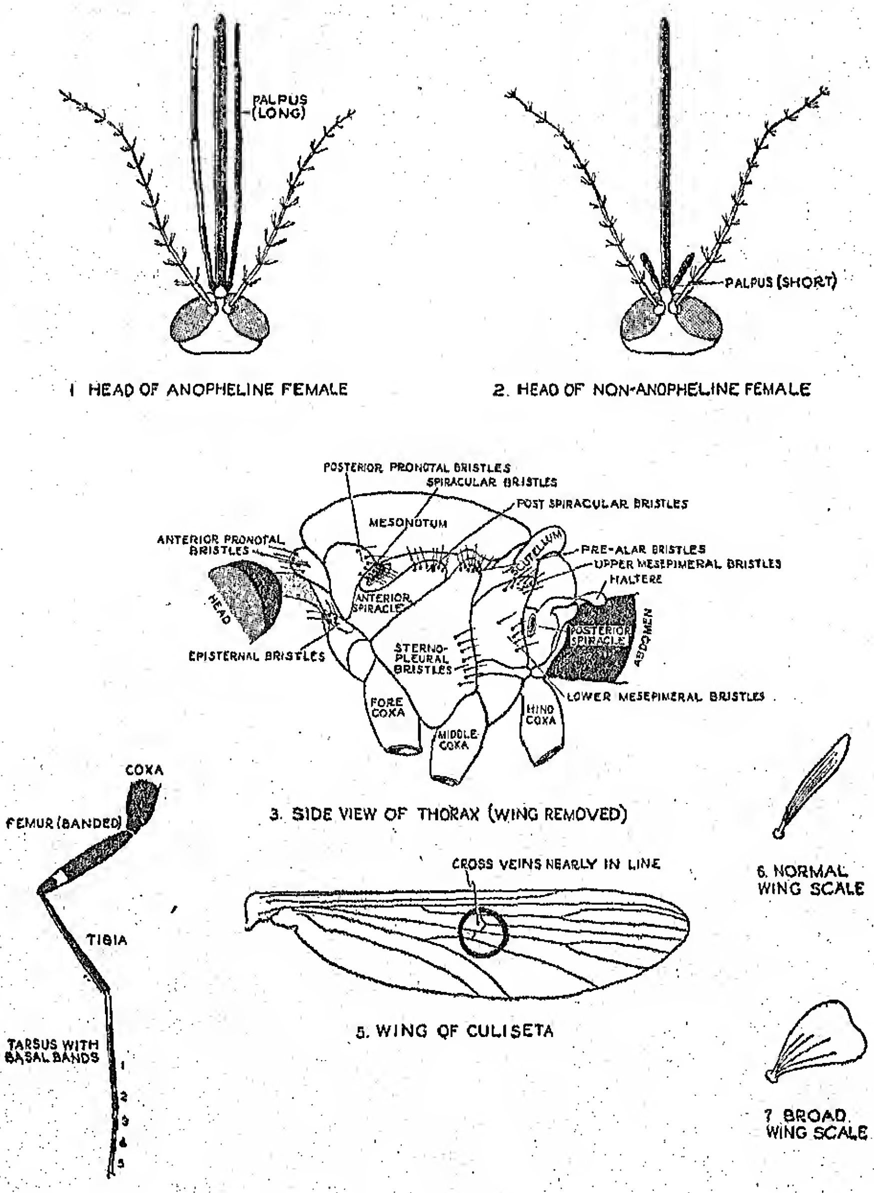
Since success in the abatement of mosquitoes (species sanitation) rests so largely on an accurate diagnosis of the offending species, the use of entomological keys becomes necessary. The terminology used in classification cannot be understood without some knowledge of the external structural details of adult mosquitoes and of their immature stages; hence there is included in this appendix a series of plates and figures illustrating the more important characters used in keys (Plates I–VII), and four diagram types of key, two circular, one pictorial, and one columnar (Plates VIII–XI). The material here presented provides a minimum of working knowledge in a highly technical field, designed for elementary instruction of persons not trained in entomological techniques. The worker in the field of mosquito abatement will need to consult technical systematic entomologists experienced in culicidology for expert advice from time to time.

There are many two-winged insects (*Diptera*) which resemble mosquitoes more or less closely, yet do not bite; chief among these are midges or gnats belonging to the Family *Chironomidae.* While these midges superficially are easily confused with mosquitoes, they can be easily separated in that the mouth-parts are rather blunt (non-piercing), the antennae (feelers) are highly plumose (bushy), and the wings are devoid of scales (see p. 96). Midges often occur in great swarms toward evening or by day in cloudy weather. The larvae of these midges are gill breathers and are generally blood red in color (commonly known as blood-worms) and remain in the bottom muck or debris in stagnant pools, ponds, reservoirs, lakes, and the like, until they are ready to emerge as adults from pupae at the surface.

Other mosquito-like insects are the *Dixa* midges (Family *Dixidae*) in which the adults have sparsely hairy antennae, wings practically bare, and the proboscis, while projecting somewhat, rather blunt and non-piercing. *Dixa* midges are non-bloodsucking. The larvae of the *Dixa* midges are aquatic and resemble mosquito larvae, especially anophelines; however, they have a particularly noticeable horizontal U-shaped position.

Gnats belonging to the Family *Chaoboridae* often occur in unbelievably great swarms along the borders of lakes. They are rather delicate, hairy, non-biting insects; the hairs on the antennae are in whorls. The larvae are known as "phantoms" because of their translucence, and swim freely rather deep in the water; they are gill breathers.

Strangely enough the members of the Family *Tipulidae* (crane-flies or daddy-long-legs) are frequently mistaken for mosquitoes. Crane-flies are long-legged insects, usually much larger than mosquitoes, and possess non-biting blunt mouth-parts and wings without scales. The larvae are called "leather



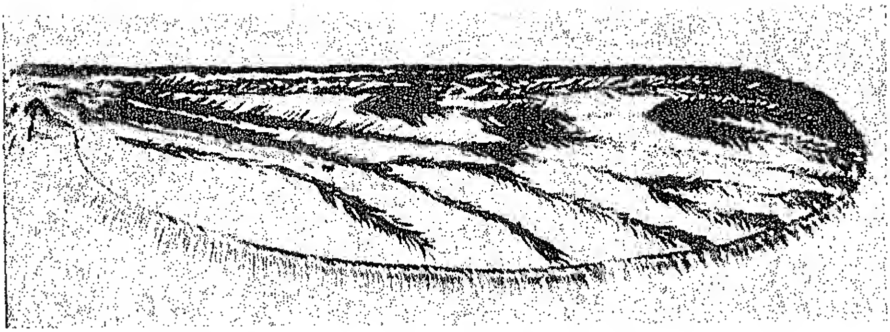

*Courtesy U. S. Public Health Service*

Plate I. Anatomical structures and markings used in keys for the identification of adult mosquitoes jackets" and usually occur in moist soil or under semi-aquatic conditions; some species exist among grass roots under dry range conditions.

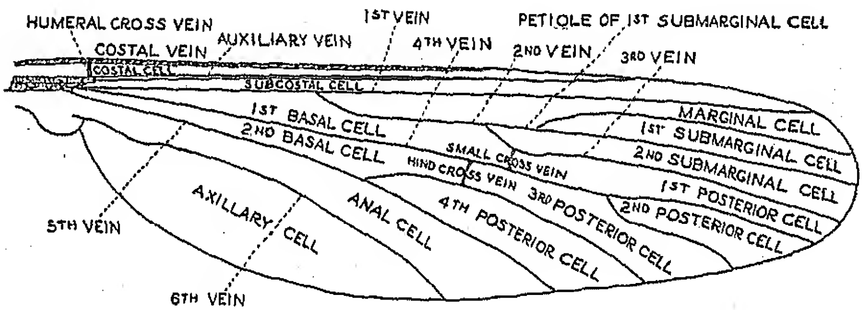
*How to recognize a mosquito.* It is in order, therefore, in view of the foregoing information, to ask "What is a mosquito?" The entomologist describes mosquitoes as slender, delicate flies (insects with one pair of wings, belonging to the Order *Diptera*) with slender legs and usually with scales upon the body and appendages; head small, sub-spherical with slender neck; eyes conspicuous and kidney shaped; antennae (feelers) long, slender, and composed of fourteen or fifteen segments, with whorls of hairs which in the males present a plumose condition; proboscis long and conspicuous in both sexes; thorax arched but not projecting over the head; scutellum (Plate I, 3) short and evenly rounded or trilobed; legs long and slender; wings long and narrow, at rest lying flat over the abdomen, venation shown in Plate II, 2, the veins and wing margin clothed with scales; halteres conspicuous; abdomen long and narrow, composed of nine or ten segments. The Family *Culicidae*, which comprises the mosquitoes, receives its name from the Latin *culex* which means gnat.

*Mosquito larvae* (wrigglers) are invariably aquatic, generally active and free swimming; they are elongated (worm-like), with head free (a complete head capsule), a slender neck and a greatly enlarged fused thorax; the abdomen is slender and ten-segmented (segments VIII and IX fused) with a pair of functional spiracles (air openings) situated dorsally on the ninth abdominal segment; spiracles open through a tube (siphon) or other modified apparatus (as in anophelines) for obtaining air through the water surface, or for puncturing submerged aquatic plants as a source of oxygen as in *Mansonia*. The head of the mosquito larva bears a pair of short, one-segmented antennae, a pair of conspicuous eyes, and variously arranged hair tufts and hairs which are of diagnostic value (see Plates V, VI, and VII). The thorax likewise possesses hair tufts and hairs which are useful in classification. The hair tufts and palmate hairs (anophelines) on the abdomen also serve diagnostic purposes as do the special structures on the air tube, the anal segment, and segments VIII and IX. It is important to know that the larvae shed their skins four times and that with the fourth molt the pupa appears, hence the larvae have four instars or stages, the first two being small and immature; full growth is reached in the fourth instar.

*The pupal stage* achieved with the fourth molt marks the completion of feeding and growth. The pupa does not feed. It is the stage in which transformation into the adult insect takes place inside of the pupa case. In this stage there is a very large cephalothorax (fused head and thorax) which bears a pair of respiratory trumpets (Figure 1, opposite page 4) and a tail-like abdomen terminating in a pair of anal paddles. Movement in the water is by a tumbling motion, hence the term "tumbler." Detailed classification of species based on pupal characteristics is not considered practical; however, the general characteristics of the respiratory trumpets afford a basis for rough classification as shown in Figure 1; the trumpets of the anophelini are short and open

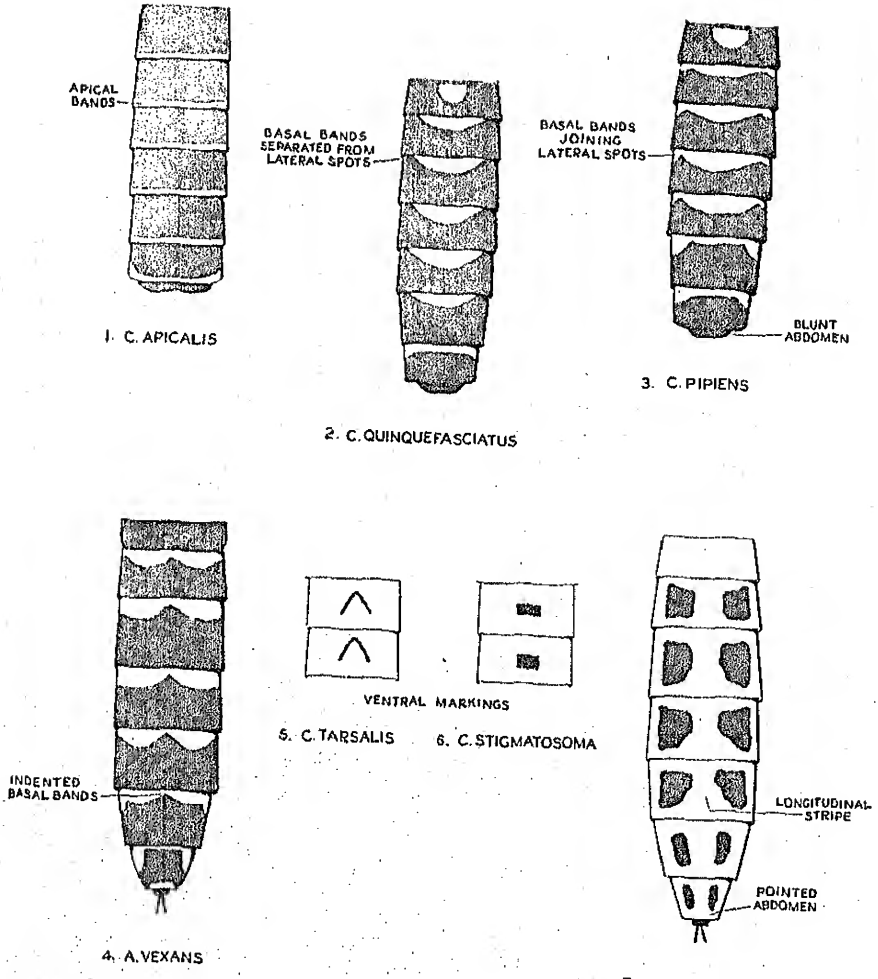


1. Photograph of the wing of *Anopheles maculipennis freeborni*, showing scales on margin and on veins




2. Diagram showing the veins and the cells of a mosquito wing, with their designations. The auxiliary vein is also designated as the subcostal vein

Plate II. The mosquito wing and wing venation




*Courtesy U. S. Public Health Service*

Plate III. Various arrangements of abdominal markings of a mosquito, useful in identification broadly, while in the culicini they are relatively long and slender. The adult mosquito which emerges from the pupal stage is *full grown*.

*Eggs* of mosquitoes show differences in pattern, ornamentation, and color, but do not lend themselves to systematic keys, perhaps particularly because of their minute size. In general it may be said that members of the culicini deposit their eggs in boat-shaped rafts (Figure 1), while the members of the aedini and anophelini deposit theirs singly (Figure 1). Color patterns on the eggs of certain species of *Anopheles* (*Anopheles maculipennis*) afford a basis for the separation of sub-species which are otherwise indistinguishable.

## USE OF KEYS

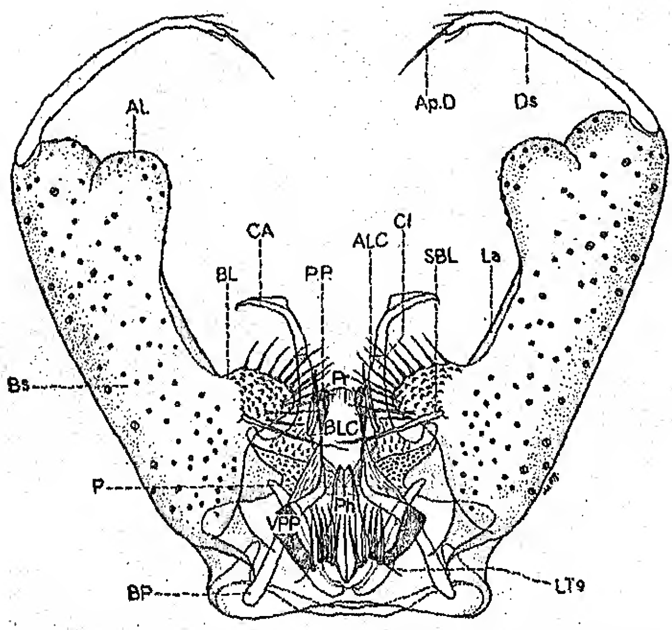
While it is not within the province of this book to provide complete keys for the identification of mosquito species, non-entomologist workers in the field of mosquito abatement should have a working knowledge of the procedures used by entomologists. A variety of schemes are used in the literature, only a few of which are here presented. However, experience in the use of these keys will enable the worker to identify the more important species in a given geographical area covered by such publications as *Identification Guide to the Mosquitoes of the Pacific Coast* by the United States Public Health Service, Malaria Control in War Areas, Atlanta, Georgia, May, 1943, and *The Mosquitoes of the Southeastern States*, Revised June, 1942, United States Department of Agriculture Publication No. 336, Washington, D. C. Other similar publications relating to various geographical areas are listed in APPENDIX E.

Examination of the external characters of adult mosquitoes requires the use of a binocular, dissecting microscope, provided with objectives and oculars giving magnifications up to about 85X. For the examination of male terminalia the oil-immersion objective will be needed. For provisional identification in the field, a hand lens giving a magnification of 10X to 15X is useful.

Having made certain that the specimen you are dealing with is a mosquito, you are then concerned with the problem of identifying it as to genus and species. For this purpose you will use a key to the identification of mosquitoes. Keys differ considerably in arrangement but, as already stated above, all require familiarity with the external structure of these insects.

A classification key is based on the procedure of selecting some definite anatomical character and, by noting marked differences therein, separating the specimen into one of two groups; then a second character is selected, and the sub-group further subdivided; this process continues until the identification of a species is arrived at.

For example, the palpi (Plate I, 1 and 2) in adult female mosquitoes may be either much shorter than the proboscis, or about as long as the proboscis. If the palpi are long, the mosquito is an anopheline; if they are short, then it may be either *Culex, Aedes*, or some other genus. To break this remainder down into the genera, another character may be used, such as the abdomen tip (Plate III, 3 and 7). If the abdomen tip is blunt, it may be either *Culex, Culiseta*,




AL, apical lobe (not present in *Anopheles*); ALC, apical lobe of claspette; ApD, appendage of dististyle; Bs, basistyle (side piece); BL, basal lobe; BLC, basal lobe of claspette; BP, basal plate; CL, claspette (harpago); CA, claspette appendage; Ds, dististyle (clasper); La, lacuna; LT9, lobe of ninth tergite; P, paramere; Ph, phallosome (aedeagus, penis); PP, paraproct; Pr, proctiger (anal lobe); SBL, spine of basal lobe; VPP, ventral arm of paraproct. (After Herms, *Medical Entomology*, 3d ed., New York, Macmillan, 1939, p. 160.)

Plate IV. The male terminalia of an *Aedes squamiger* mosquito

or *Mansonia;* if it is pointed, it may be either *Aedes* or *Psorophora.* Other characters are then selected to make distinctions between these genera. Finally, various characters are selected to make determinations as to species within each genus. In many cases it may be necessary to use the characteristics of the male genitalia for the final and determinative identification.

*Male terminalia.* The most critical differences appropriate for the identification of adult mosquitoes are to be found in the male terminalia. The specimen one has identified by the use of a key can be positively checked by a critical study of the terminalia of the male. It is of importance to know that the terminal portion of the abdomen of the adult male begins to rotate on its axis within a few hours after emergence from the pupa and a rotation of 180 degrees is completed in from twelve to twenty-four hours. This portion of the abdomen remains upside down for the rest of the mosquito's life.

To prepare the male terminalia (see Plate IV) for study, the tip of the abdomen is clipped off with fine scissors and dropped into a dish of 70 to 95 per cent alcohol. After wetting in the alcohol the specimen is transferred to 10 to 20 per cent KOH for five to twenty minutes and then to a slide where the excess KOH is removed by blotting from the edge of the liquid; next a drop of glacial acetic acid is added and the excess removed by blotting; finally a small drop of chloral-gum is put upon the specimen and covered with a cover slip. After drying in an oven the cover slip may be sealed with clarite or brunswick black.

The male terminalia of *Anopheles* mosquitoes frequently present difficulties which may require special manipulation; however, when prepared as here described the specimen is then ready for examination with a compound microscope. Plate IV shows the various elements diagrammatically.

There are no satisfactory keys based on the structures of the male terminalia. Hence one will make a tentative identification in the usual manner, that is, by using keys as already described, and will then endeavor to confirm the identification by consulting publications such as Ross and Roberts, *Mosquito Atlas*, Parts I and II (see APPENDIX E), in which male terminalia of the various species are fully illustrated.

As an aid to identification there should be available to the technical workers a collection of specimens from the locality where the project is being carried on, which have been identified and labeled by a competent culicidologist.

### *Key to the Genera of Adult Female Mosquitoes*

Adapted from *Identification Guide to the Mosquitoes of the Pacific Coast*, United States Public Health Service, Malaria Control in War Areas, Atlanta, Georgia, May, 1943.

Palpi of females more than one-half length of proboscis (Plate I, 1)
*Anopheles*

Abdomen of females blunt (Plate III, 8); palpi short (Plate I, 2)

*Culiseta*
Cross-veins nearly in a line (Plate I, 5); spiracular bristles (Plate I, 8)

*Orthopodomyia*
Fourth tarsal segment of foreleg as wide as long; mesonotum with delicate silvery pattern; no spiracular bristles; rare. *O. signifera* (Coq)

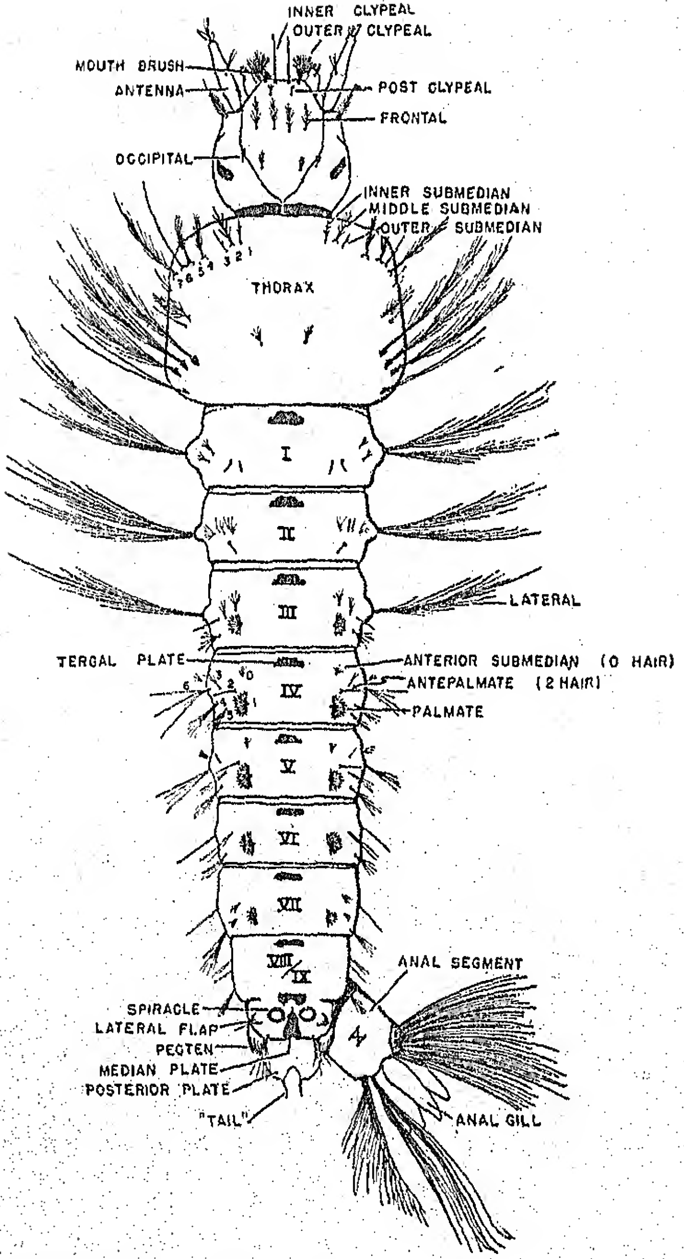
*Culex*
Cross-veins separated by own length; no spiracular bristles; normal, narrow wing scales (Plate I, 6)

*Mansonia*
Broad, bi-colored wing scales (Plate I, 7); very fuzzy; no spiracular bristles. *M. perturbans* (Walker)

Abdomen pointed (Plate III, 7); palpi short (Plate I, 2)

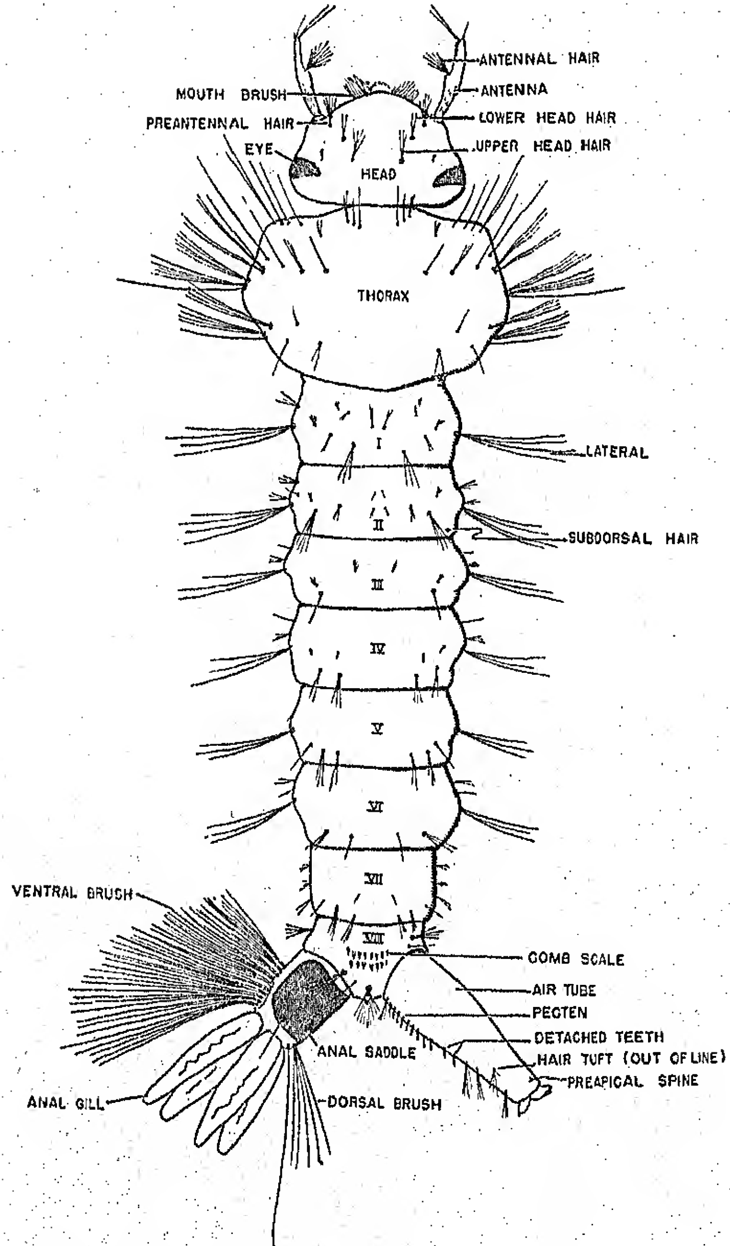
*Aedes*
No spiracular bristles; common

*Psorophora*
Spiracular bristles (Plate I, 8); rare; S.E. California. *P. confinnis*



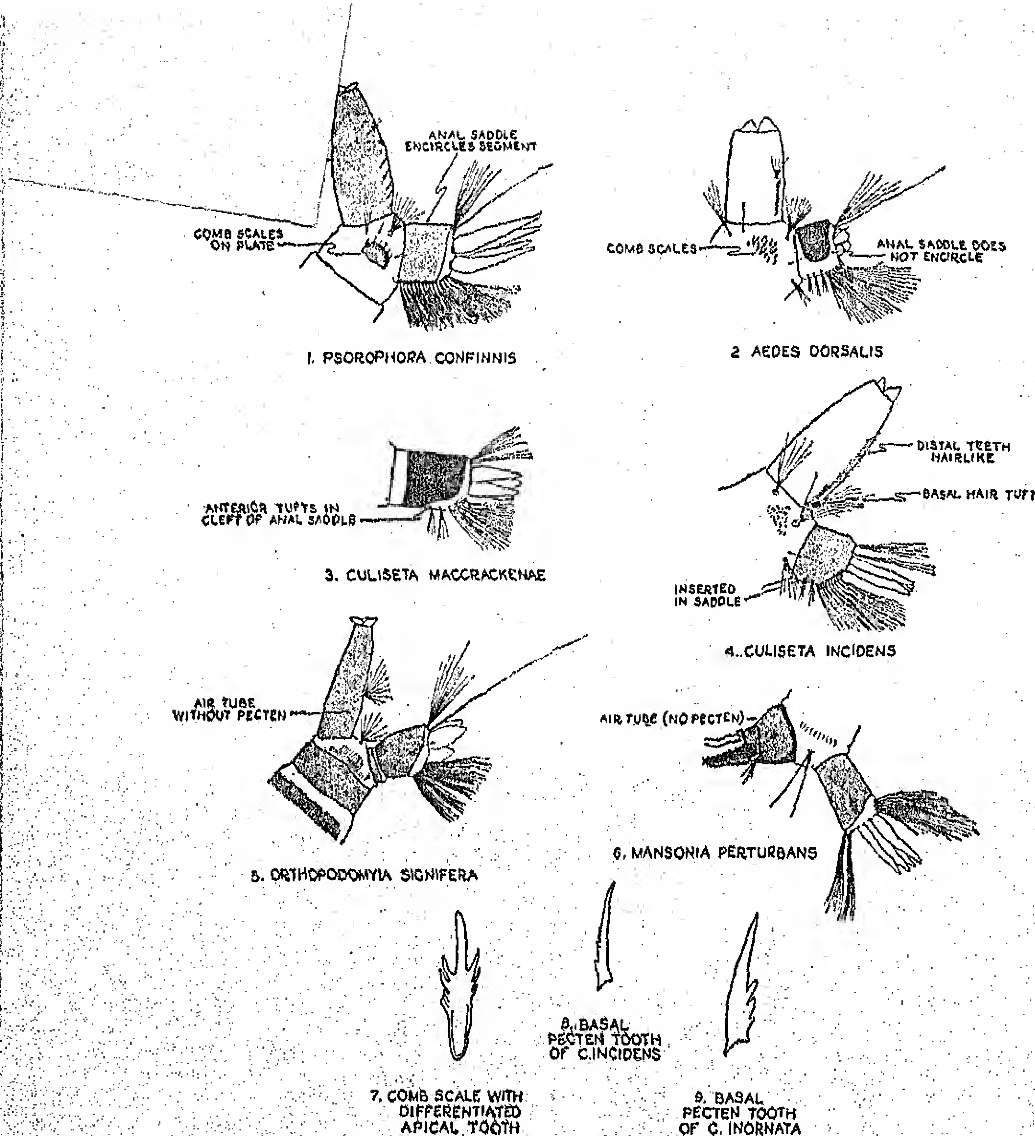

*Courtesy U. S. Public Health Service*

Plate V. Diagram of an anopheline larva




*Courtesy U. S. Public Health Service*

Plate VI. Diagram of a culicine larva




*Courtesy U. S. Public Health Service*

Plate VII. Terminal structures of culicine larvae, showing characters useful in identification of genera and species

### *Key to the Larvae (Genera)*

Without a tubular air tube (Plate V)
*Anopheles*

With a tubular air tube (Plate VI)
Air tube without pecten (Plate VII, 5 and 6)

*Orthopodomyia*
Tree-hole breeder (Plate VII, 5)

*Mansonia*
Root breeder with saw-like projection of air tube (Plate VII, 6)

Single pair of multiple hair tufts on the air tube
*Culiseta*
Hair tuft situated within basal third of regular portion of pecten (Plate VII, 4); all except *morsitans* with distal pecten teeth produced into long setae

*Aedes*
Hair tuft beyond regular portion of pecten, sometimes within pecten; eighth segment comb scales inserted individually (Plate VII, 2)

*Psorophora*
Air tube swollen; eighth segment comb scales arising from plate (Plate VII, 1)

Usually more than one pair of hair tufts on air tube; if a single pair only, it is distal and with other tufts represented by hairs; if none, the tufts are represented by single hairs (*thriambus, restuans*)
*Culex*

### *Illustrating Couplet Scheme for Identification of Adult Mosquitoes of the Genus* Culex *of the Southeastern States*

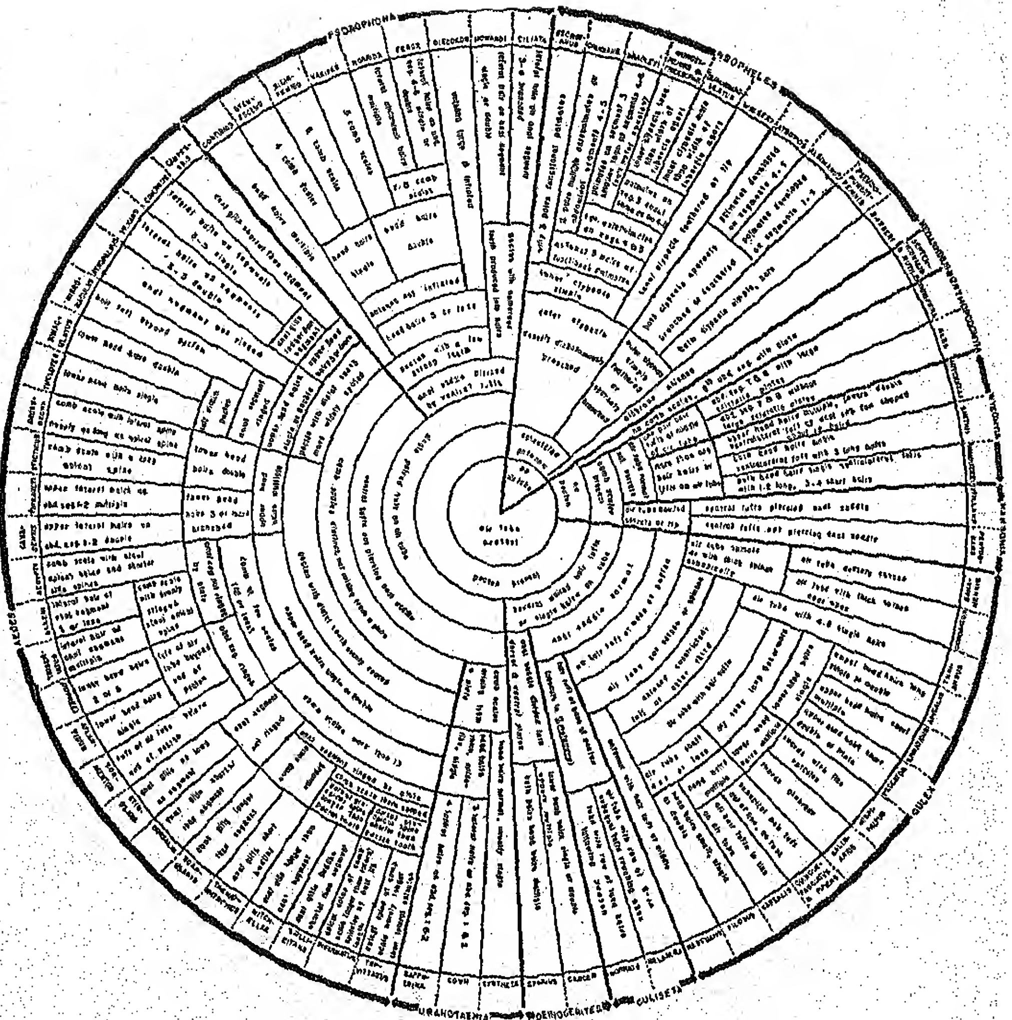
The use of the couplet scheme for the identification of female adult mosquitoes is illustrated in the following excerpt adapted from King *et al.** A mosquito belonging to the genus *Culex* will be used for this purpose, the genus being recognized by the following characters: the palpi much shorter than the proboscis, which is straight or only slightly curved, not tapered; the second marginal cell (Plate II, 2) of the wing as long or longer than its petiole (Plate II, 2); scutellum (Plate I, 3) trilobed; post-spiracular (Plate I, 3) bristles present; tip of abdomen blunt (Plate III, 1, 2, and 3); the tarsi (Plate I, 4) not ringed with white, and mesonotum (Plate I, 3) without distinct markings (except small white dots in *Culex restuans*); the antennae normal, not longer than the proboscis, first flagellar segment of about the same length as succeeding ones.

* King, W. V., Bradley, G. H., and McNeel, T. E. *The Mosquitoes of the Southeastern States.* Washington, D. C.: United States Department of Agriculture, Miscellaneous Publication No. 336, Revised June, 1942.

18. Dorsal abdominal white bands or lateral spots basal when present ............ 19
Abdomen with narrow dorsal bands and (or) lateral spots of white scales on apical (posterior) margin of segments (Plate III, 1) ................ *Culex apicalis*
19. Abdomen dorsally banded with conspicuous segmental bands of white scales; seventh segment without pale scales posteriorly; occiput with narrow, curved scales (Plate I, 6); outstanding wing scales narrow ...................... 20
Abdomen unbanded dorsally or with narrow segmental bands; fairly broad bands of yellowish scales sometimes present in *C. salinarius* .................... 22
20. Abdominal bands with a rounded posterior border (usually most typical on segments III to V) and the bands interrupted or much narrowed at lateral margins (Plate III, 2)
Mesonotum without dots; mesonotal vestiture of narrow, curved, or lanceolate scales (Plate I, 6), pale-brown or grayish and having a coarse appearance; second marginal cell (Plate II, 2) usually two-and-a-half to three times the length of its petiole. The southern house mosquito ........... *Culex quinquefasciatus*
Abdominal bands continuous to lateral margins (Plate III, 3), their posterior borders somewhat irregular but not evenly rounded; second marginal cell (Plate II, 2) long, usually four or five times as long as its petiole ................. 21
21. Mesonotum (Plate I, 3) usually with a pair, sometimes two pairs, of small white dots near the middle and with grayish scales around the margins; mesonotal vestiture otherwise brownish and with a smooth appearance, mostly of fine hair-like scales ........................................ The white dotted *Culex*
*Culex restuans*
Mesonotum (Plate I, 3) without white dots; mesonotal scales coarser and grayish in color similar to *C. quinquefasciatus*. The northern house mosquito, found in northern Tennessee and North Carolina ...................... *Culex pipiens*
22. Wings with all outstanding scales long and slender (Plate I, 6); occiput (top part of head back of eyes) without flat scales; mesonotum (Plate I, 3) with very fine, dark-brown hair-like scales. Medium sized species ......................... 23
Outstanding scales of wing, at least on branches of vein 2 (Plate II, 2) slightly or distinctly broadened; occiput with some broad flat scales (except in *Culiseta melanura*) .................................................................. 24
23. Abdomen usually with a few yellowish or dingy white scales at base of some segments, or with narrow transverse bands; tips of segments sometimes slightly pale-scaled and seventh segment frequently entirely pale-scaled; three or four groups of white scales on side of thorax. Abundant in some sections of the South and East ................................................ *Culex salinarius*
Abdomen dark-scaled above except for lateral white spots on some segments; scaling on pleurae (the sides of the insect) somewhat variable but frequently entirely lacking or, if present, limited as a rule to less than half a dozen scales in any of the groups. Abundant in Florida, rare elsewhere ...... *Culex nigripalpus*
24. Occiput with broad, dusky or pale, appressed scales in front, sometimes limited to a narrow border along the eyes, but extending to or nearly to vertex; abdominal segments with or without narrow white bands. Small *Culex*, sub-genus *Melanoconion* .................................................................. 25
Occiput without flat scales. Proboscis unusually long (longer than abdomen); wing scales dense and distinctly broadened; spiracular bristles (Plate I, 3) and ventral setae at base of subcostal vein (Plate II, 2) present as in *Culiseta inornata* (lacking in all *Culex*). A comparatively rare species, greatly resembling typical *Culex* ................................................ *Culiseta melanura*
25. Occiput mostly covered with broad appressed scales (Plate I, 7), the narrow scales (Plate I, 6) limited to a median line or a small triangular patch. (Tip of male

abdomen much enlarged in *Culex peccator*) .................... *Culex pilosus*
*Culex peccator*

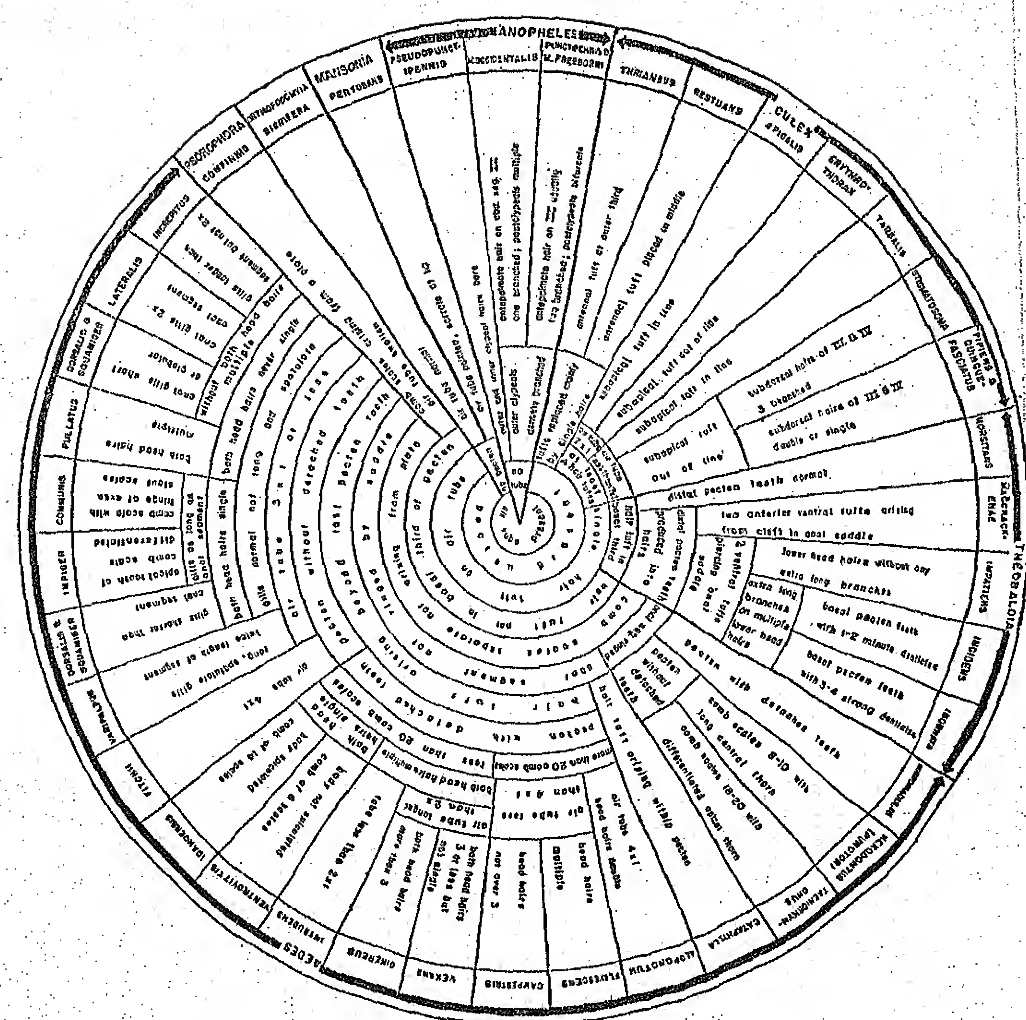
Occiput with a large median triangular area of narrow scales (Plate I, 6) extending nearly to the vertex, the broad appressed scales (Plate I, 7) often reduced to a narrow line bordering the eyes. (Mesonotal scaling often bronzy or golden)
*Culex erraticus*




Proceed outward from the center, following the alternative choices arranged in the concentric circles. By proceeding inward from the circumference the distinctive characters of any species may be determined.

*Courtesy U. S. Public Health Service*

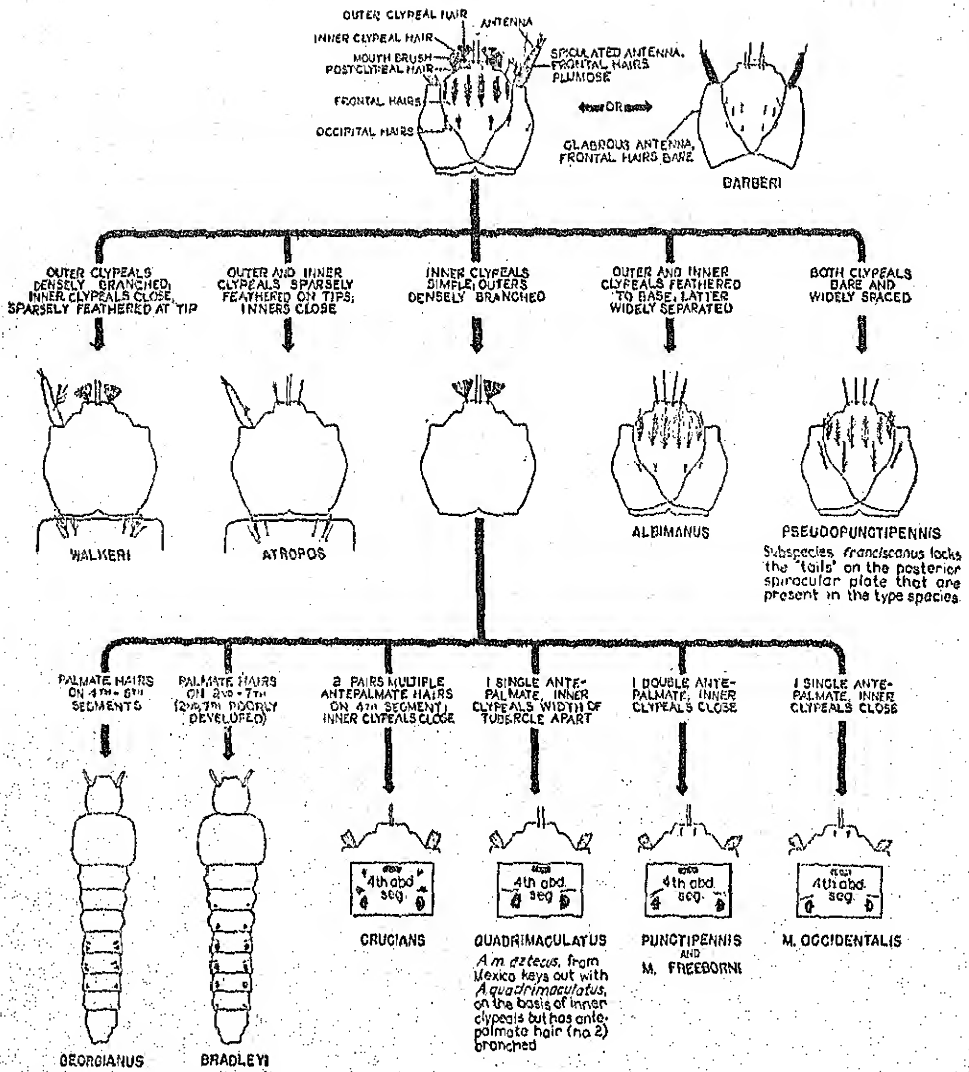
Plate VIII. Key to the mosquito larvae of the southern United States, by G. H. Bradley, S. B. Freeborn, and E. J. Gerberg (circular diagram type)




Proceed outward from the center, following the alternative choices arranged in the concentric circles. By proceeding inward from the circumference the distinctive characters of any species may be determined.

*Courtesy U. S. Public Health Service*

Plate IX. Key to the mosquito larvae of the Pacific Coast (circular diagram type)




*Courtesy U. S. Public Health Service*

Plate X. Key to the Nearctic anopheline larvae of America (pictorial diagram type)

| sergenti | superpictus | hispaniola italicus | multicolor | d'thalia | pharoensis | coustani | hyrcanus | plumbeus | claviger | marteri | algeriensis | sacharovi | maculipennis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N. Africa oases carrier | Italy to Asia ++carrier | Spain and Italy respectively ? carriers | N. Africa Palestine + carrier | S. & E. Medit. Arabia carrier | Egypt Palestine | Egypt Palestine | N. Medit. Balkans to Orient | Eur-tree holes | Eur., N. Africa to Turkey-carrier in Near East | Algeria Macedonia hill streams ? carrier | So. Eur. N. Africa Nr. East ? carrier | Balkans Nr. East + + + carrier | Widely spread; atroparvus and labranchiae + + carriers |
| Distal palpal segment half as long as 3rd. Base of costa dark. | Distal palpal segment nearly as long as 3rd. Base of costa pale. | Thorax without distinct scales. Base of costa dark. | Thorax with distinct scales. Base of costa pale. | | Important carrier of Nile Delta | ? carrier | Not important in our area | Small, black, distal palpal segment more than 1/2 length of third | Large, brown, distal palpal segment less than 1/2 length of third | | | | |
| | | | | | | | | Proboscis dark tipped | | Proboscis white tipped | | | |
| Tip of palpi pale | | Tip of palpi dark | | | | | | Mesonotum with central pale area; white frontal tuft present | | | No pale mesonotal stripe; no white frontal tuft. | Wing fringe without pale patch at apex. | Wing fringe with pale patch at apex. |
| Pale wing scales distributed over wing | | | | Pale wing scales confined to anterior portion | | Last two segments of hind tarsus white | Last segment only of hind tarsus white | Wing scales uniformly distributed; no dark spots | | | | Wing scales clumped to form spots | |
| Last segment of hind tarsus dark | | | | | Last segment of hind tarsus white. | Wing scales bi-colorous | | Scales on wing proper uniform in color | | | | | |
| Costal margin with more than two distinct pale areas | | | | | | Costal margin without more than two distinct pale spots | | | | | | | |

*Courtesy U. S. Public Health Service*

Plate XI. Key to adult anophelines in countries bordering the Mediterranean (columnar diagram type)

## Appendix E

# SELECTED LIST OF BOOKS AND ARTICLES ON MOSQUITO SPECIES AND BIOLOGY

The following list of publications on mosquitoes includes valuable information for all workers concerned with mosquito abatement.

### GENERAL

Blanchard, R. Les moustiques: histoire naturelle et médicale. Paris: F. R. de Rudeval, 1905. i–xiii + 673 p., 316 figs.

Christophers, S. R. Provisional list and reference catalogue of the Anophelini. Indian Medical Research Memoir (Calcutta), No. 3, December, 1924. 105 p.

Edwards, F. W. Diptera, family Culicidae. Genera insectorum. (P. Wytsman.) Brussels: L. Desmet-Verteneuil, 194me fascicule, 1932. 256 p., plates I–V.

Laboratory guide to medical entomology, with notes on malaria control. Bethesda, Maryland: Naval Medical School, Department of Tropical Medicine and Parasitology, National Naval Medical Center, 1943. 193 p.

Russell, P. F., Rozeboom, L. E., and Stone, A. Keys to the anopheline mosquitoes of the world, with notes on their identification, distribution, biology and relation to malaria. Philadelphia: American Entomological Society; Academy of Natural Sciences; 1943. 152 p.

Theobald, F. V. A monograph of the Culicidae or mosquitoes. Vol. I, 1901, 424 p., 151 figs.; vol. II, 1901, 391 p., 318 figs.; vol. III, 1903, 359 p., 193 figs., plates I–XVII; vol. IV, 1907, 639 p., 297 figs., plates I–XVI; vol. V, 1910, 646 p., 261 figs.; plates, 1901. London: British Museum (Natural History).

Weyer, F. Die Malaria-Überträger. (Eine Zusammenstellung der wichtigen Anopheles-Arten mit Angaben über Verbreitung, Brutgewohnheiten, Lebensweise und praktische Bedeutung.) Leipzig: Georg Thieme, 1939. 141 p., 15 figs.

### NORTH AND CENTRAL AMERICA

Aitken, T. H. G. The Anopheles complex in California (Diptera, Culicidae). Proceedings of the Sixth Pacific Science Congress, IV, 1939. p. 463–484.

Aitken, T. H. G. Contributions toward a knowledge of the insect fauna of Lower California, No. 6: Diptera: Culicidae. Proceedings of the California Academy of Sciences, 24:161–170, June, 1942.

Bradley, G. H. On the identification of the mosquito larvae of the genus Anopheles occurring in the United States (Diptera, Culicidae). Southern Medical Journal, 29:859–861, August, 1936. 5 figs.

Bradley, G. H., and King, W. V. Bionomics and ecology of Nearctic Anopheles. A symposium on human malaria. Washington, D. C.: American Association for the Advancement of Science, 1941. p. 79–87.

Carpenter, S. J. The mosquitoes of Arkansas. Little Rock: State Board of Health, 1939. 89 p., 31 figs., 2 tables.

Causey, O. R. Neotropical Anophelini, common species of the United States included (key to adults and larvae). Bethesda, Maryland: Naval Medical School, National Naval Medical Center, December, 1942. 15 p.

Dyar, H. G. The mosquitoes of Canada. Transactions of the Royal Canadian Institute, 13:71–120, February, 1921.

Dyar, H. G. The mosquitoes of the United States. Proceedings of the United States National Museum, 62:1–119, June, 1922.

Dyar, H. G. The mosquitoes of Panama. Insecutor Inscitiae Menstruus (Washington, D. C.), 13:101–195, July, 1925.

Dyar, H. G. The mosquitoes of the Americas. Washington, D. C.: Carnegie Institution of Washington, Publication No. 387, May, 1928. 616 p., plates I–CXXIII.

Freeborn, S. B. The mosquitoes of California. Berkeley: University of California Agricultural Experiment Station, Technical Bulletins. Entomology, 3:336–460, March, 1926. 41 figs.

Freeborn, S. B., and Brookman, B. Identification guide to the mosquitoes of the Pacific Coast states. Atlanta, Georgia: United States Public Health Service, Malaria Control in War Areas, May, 1943. 23 p.

Hearle, E. The mosquitoes of the lower Fraser Valley, British Columbia, and their control. Ottawa: National Research Council, Report, 1926, No. 17. 94 p., plates I–XIV.

Howard, L. O., Dyar, H. G., and Knab, F. The mosquitoes of North and Central America and the West Indies. Washington, D. C.: Carnegie Institution of Washington, Publication No. 159. Vol. I, 1912, 520 p., plates I–XIV; vol. II, plates, 1912; vol. III, 1915, p. 1–524; vol. IV, 1917, p. 524–1064.

King, W. V., and Bradley, G. H. General morphology of Anopheles and classification of the Nearctic species. A symposium on human malaria. Washington, D. C.: American Association for the Advancement of Science, 1941. p. 63–70.

King, W. V., and Bradley, G. H. Distribution of the Nearctic species of Anopheles. A symposium on human malaria. Washington, D. C.: American Association for the Advancement of Science, 1941. p. 71–78.

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King, W. V., Bradley, G. H., and McNeel, T. E. The mosquitoes of the southeastern states. Washington, D. C.: Department of Agriculture, Miscellaneous Publications No. 336, June, 1942. 96 p.

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Komp, W. H. W. The anopheline mosquitoes of the Caribbean region. Washington, D. C.: National Institute of Health, Bulletin No. 179, 1942. 195 p.

Kumm, H. W., and Ram, L. M. Observations on the Anopheles of British Honduras. American Journal of Tropical Medicine, 21: 559–566, 1941.

Mail, G. A. The mosquitoes of Montana. Bozeman: Montana Agricultural Experiment Station, Bulletin No. 288, March, 1934. 72 p., 18 figs.

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Matheson, R. A handbook of the mosquitoes of North America. Springfield, Ill.: C. C. Thomas, 1929. i–xviii + 274 p., 23 figs., plates I–XXV.

Moulton, F. R., Editor. A symposium on human malaria, with special reference to North America and the Caribbean region. Washington, D. C.: American Association for the Advancement of Science, 1941. viii + 398 p.

Owen, W. B. The mosquitoes of Minnesota, with special reference to their biologies. St. Paul: University of Minnesota Agricultural Experiment Station, Technical Bulletin No. 126, November, 1937. 75 p., 11 figs.

Rees, D. M. The mosquitoes of Utah. Salt Lake City: Bulletin of the University of Utah, Vol. 33, No. 7, March 4, 1943. 99 p.

Ross, E. S., and Roberts, H. R. Mosquito atlas, Part I: the Nearctic Anopheles; important malaria vectors of the Americas and Aedes aegypti, Culex quinquefasciatus. Philadelphia: American Entomological Society; Academy of Natural Sciences, 1943. iv + 44 p.

Rowe, J. A. Notes on the distribution and breeding habitats of Iowa Anopheles. Journal of the Iowa State Medical Society, 31:279–280, July, 1941.

Rozeboom, L. E. The mosquitoes of Oklahoma. Stillwater: Oklahoma Agricultural and Mechanical College, Technical Bulletin No. T–16, October, 1942. 56 p.

Simmons, J. S., and Aitken, T. H. G. The anopheline mosquitoes of the northern half of the western hemisphere and of the Philippine Islands. Washington, D. C.: Army Medical Bulletin No. 59, January, 1942. 213 p.

Tulloch, G. S. A key to the mosquitoes of Massachusetts. Psyche (Boston), 46: 113–136, December, 1939. Plates IV–VIII.

Vargas, L. Clave para identificar las larvas de Anopheles Mexicanos. Ciencia, 1:66–68, April 1, 1940.

### SOUTH AMERICA

Bonne, C., and Bonne-Wepster, J. Mosquitoes of Surinam, a study on neotropical mosquitoes. Koninklijke vereeniging het Koloniaal Instituut te

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Cova-Garcia, P. Notas sobre los anofelinos de Venezuela y su identificacion. Caracas: Publicaciones de la Division de Malariologia No. 2 (Ministerio de Sanidad y Asistencia Social), January, 1939. 84 p., plates I–X, 5 tables.

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Macan, T. T. A key to the anopheline mosquitoes of the Mediterranean region and the lands adjoining the Red Sea and the Persian Gulf. Journal of the Royal Army Medical Corps, 79:1–11, July, 1942.

Marshall, J. F. The British mosquitoes. London: British Museum (Natural History), 1938. i–xi + 341 p., plates I–XX.

Ross, E. S., and Roberts, H. R. Mosquito atlas, Part II: eighteen Old World anophelines important to malaria. Philadelphia: American Entomological Society; Academy of Natural Sciences, 1943. iv + 44 p.

Séguy, E. Histoire naturelle des moustiques de France. Paris: Paul Lechevalier, 1923. 225 p., 201 figs.

Sinton, J. A., and Shute, P. G. Memorandum on measures for the control of mosquito nuisances in Great Britain. Ministry of Health. London: His Majesty's Stationery Office, 1943. 32 p.

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Barraud, P. J. The fauna of British India, including Ceylon and Burma. Diptera, vol. V, family Culicidae, tribes Megarhinini and Culicini. London: Taylor and Francis, 1934. i–xxviii + 463 p., 106 figs., plates I–VIII, 1 map.

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Causey, O. R. Some anopheline and culicine mosquitoes of Siam with remarks on malaria control in Bangkok. American Journal of Hygiene, 25: 400–420, 1937.

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Edwards, F. W. A synopsis of adult oriental culicine (including megarhinine and sabethine) mosquitoes. Parts I and II. Indian Journal of Medical Research (Calcutta), 10:249–293, 430–475, July and October, 1922.

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